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Research Article

Optimization Algorithm of Control Channel Selection for Wireless Networks

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Control channel is used to transmit protocol or signal information between wireless network nodes and is a key component of wireless network. Compared with data information, protocol or signal information is usually much less, so the spectrum bandwidth requirement of control channel is also much less than that of data channel. In order to optimize the usage of the limited spectrum resources, this paper focuses on the issue of control channel selection. We propose a greedy algorithm which minimizes the total spectrum bandwidth of the set of control channels. Theoretical analysis proves that the proposed algorithm can achieve the optimal set of control whose sum of the spectrum bandwidth is the minimum. Simulation results also show that the proposed algorithm consumes less spectrum resources than other algorithms in the same wireless network environment.

1. Introduction

Recently, with the rapid development of the wireless communication technology, wireless network has been the most important infrastructure in the daily life. In order to organize each node in wireless networks to work together, control channel is used to transmit protocol or signal information between wireless network nodes and is a key component of wireless network. Control channel is usually divided into two categories: in-band control channel and out-of-band control channel. The in-band control channel means that protocol or signal information is transmitted in the same channel with data information. On the contrary, out-of-band control channel is different from the channel used to transmit data information. Channel assignment [1–4] is a very important issue for reducing interference and improving throughput in wireless networks, and the generation and selection of control channel are the base for solving this issue. In this paper, we study the issue of optimal selection of out-of-band control channel.

In wireless networks, each node needs to select one channel from its available channels as the control channel to transmit protocol or signal information with its neighbor nodes. To transmit protocol or signal information, each control channel needs to occupy spectrum bandwidth. The problem is how to select the set of control channels for the whole wireless network which minimizes the total spectrum bandwidth of the control channels. If all nodes in wireless networks have the same available channels, the channel with the minimum spectrum bandwidth will be selected as the control channel. However, in real wireless networks, the available channel set of each node may be different. For example, in cognitive wireless networks, due to the geographical location difference and activity of primary user, the available channel set of each node is quite different, and the spectrum bandwidth of each available channel is also different. In this paper, we set the spectrum bandwidth as channel weight and propose a greedy algorithm to solve the problem of optimal selection of control channel under the constraint of different nodes with different available channel sets. The proposed algorithm is composed of two parts. In the first part of the algorithm, we delete the wireless network node whose accessible channel set completely includes that of some other nodes. Then, in the second part of the algorithm, we iteratively choose the channel which has the minimum spectrum bandwidth in an accessible channel set containing the maximum spectrum bandwidth in the current iteration.

The problem of the optimal control channel selection and related research methods which are also akin to self-organization and evolutionary game theory have been paid attention widely [5–20]. Zhong has proposed an optimal algorithm for this problem [21]. But it assumes that all of the channels have the same spectrum bandwidth. However, in reality, different channels maybe have different spectrum bandwidths. To address this issue, we design a greedy algorithm to minimize the total spectrum bandwidth of the control channels. Theoretical analysis shows that our proposed algorithm can achieve the optimal control channels, where sum of the spectrum bandwidth is the minimum with the time complexity of $O(n^2)$.

2. Preliminaries

(1) To solve the selection of the control channel, we make the following assumptions.

   (a) Each of the wireless network nodes has a set of the available channels. In this paper, the spectrum bandwidth occupied by the channel is monotonous. We assume that, as long as the index of the channel is bigger, the spectrum bandwidth it occupies is bigger.

   (b) Wireless network nodes can transmit protocol or signal information with one another through their common control channels. Note that our objective is to find the optimal set of control channels with the sum of spectrum bandwidth as small as possible.

   Let D be the set of the wireless network nodes; that is, $D = 1, 2, \ldots, n$, and let T be the set of available channels; that is, $T = L,\ L+1, \ldots, U$ (here $L < U$). For each node $i \in D$, the channels that can be accessed are l_i through u_i; that is, $l_i, l_{i+1}, \ldots, u_i$. A function for the spectrum bandwidth of each channel $\omega : T \rightarrow Q$ has the monotonously increasing property.

(2) The objective is to find a subset C of control channels T with the minimum sum of spectrum bandwidths B; that is, for all $i \in D$, $\exists c \in C$, such that $l_i \leq c \leq u_i$ holds and $B = \sum_{c \in C} \omega(c)$ is minimum.

3. Algorithm Overview

We describe the algorithm in this section. For an arbitrary instance, the wireless network nodes D and the channels set T with the associated function ω are all given. The pseudocode of the algorithm is presented as Algorithm 1.

4. Analysis of the Algorithm

For showing that the output of the algorithm is optimal, we first give the following lemma.

Lemma 1. *When the algorithm terminates, C is a subset of T such that, for any $k \in D$, there exists $c \in C$, s.t., $l_k \leq c \leq u_k$.*

Proof. Let the value of D be D_0 after Steps (1)–(5). We first prove that, for any $k \in D_0$, there exists $c \in C$ such that $l_k \leq c \leq u_k$. Note that, for any $k \in D_0$, there is an iteration which removes k from D_0. Then there are two possible cases in this iteration from Steps (8)–(14).

(1) If $i = k$, k will be removed from D_0 and l_k is added to C. Hence $l_i = l_k \in C$.

(2) If $i \neq k$, then we have $u_k \geq l_i$ since u_k is removed from D_0 in this iteration according to the algorithm. Furthermore, we should have $l_k \leq l_i$, otherwise we would have $l_i \leq l_k \leq u_k \leq u_i$, since $i \leftarrow \arg\max_{i \in D}\{u_i\}$, where D is the left nodes in the current iteration. However, in such a case i should have been removed in Steps (1)–(5), which is a contradiction. To sum up, we have $l_k \leq l_i \leq u_k$ and $l_i \in C$.

To conclude the above two possible cases, we get that, for any $k \in D_0$, we have $c \in C$ such that $l_k \leq c \leq u_k$. For any $k \in D - D_0$, there must exist $i \in D_0$ such that $l_k \leq l_i$ and $u_i \leq u_k$ from Steps (1)–(5). According to the above conclusion, we get that there must exist $c \in C$ such that $l_k \leq l_i \leq c \leq u_i \leq u_k$. This completes the proof of the lemma. □

Then the main result of the paper is presented as follows.

Theorem 2. *The subset C of T is the optimal control channels with the minimum spectrum width and the time complexity of the algorithm is $O(n^2)$.*

Proof. We first claim that C is a subset of T with the smallest cardinality such that, for all $i \in D$, there exists $c \in C$, such that $l_i \leq c \leq u_i$.

From the proof of Lemma 1, $D_0 \subseteq D$ and the algorithm outputs a subset C such that, for all $k \in D_0$, there exists $c \in C$ such that $l_k \leq c \leq u_k$. Considering any subset C_x of T such that, for all $i \in D_0$, there exists $c \in C_x$ such that $l_i \leq c \leq u_i$. Now sort the elements of C_x in decreasing order: $e_1, e_2, \ldots, e_{|C_x|}$.

By induction, we show that $e_i \geq f_i$, for all $i = 1, 2, \ldots, |C_x|$, where f_i is the element added into C in the ith iteration of the "While" cycle in the algorithm.

From the algorithm we define $f_1 = l_{i_1}$, where $i_1 = \arg\max_{i \in D_0} u_i$. Provided that $e_1 < f_1$, then, for all $i > 1$, $e_i < f_1$ according to the algorithm. Hence, there is no $c \in C_x$ such that $l_{i_1} \leq c \leq u_{i_1}$, which is a contradiction. Then $e_1 \geq f_1$. Suppose that $e_k \geq f_k$, where $k \geq 1$. Let the value of D_0 be D_k at the end of the kth iteration. Therefore, $f_{k+1} = l_{i_{k+1}}$, where $i_{k+1} = \arg\max_{i \in D_k} u_i$. Suppose that $e_{k+1} < f_{k+1}$; then we have $e_{k+1} < l_{i_{k+1}}$. On the other hand, for all $j \leq k$, then $e_j \geq e_k \geq f_k = l_{i_k}$. According to the algorithm, we have $l_{i_k} > u_{i_{k+1}}$ (otherwise i_{k+1} would have been removed from

Optimization Algorithm of Control Channels Selection

Input: $D, T, \omega : T \rightarrow Q^{+}$;

Output: The optimal control channels set C with the minimum sum of bandwidth B;

(1) For $\forall i, j \in D, i \neq j$;
(2)   If $l_i \le l_j \le u_j \le u_i$ then
(3) $D \leftarrow D - \{i\}$;
(4)   End If;
(5) End For;
(6) $C \leftarrow \emptyset$ and the initial sum of the spectrum bandwidth $B := 0$;
(7) While $D \neq \emptyset$ do
(8) $i \leftarrow \arg\max_{i \in D} \{u_i\}$;
(9) $C \leftarrow C \cup \{l_i\}$, $D \leftarrow D - \{i\}$ and $B := B + \omega(l_i)$;
(10)   For $\forall j \in D$ and $j \neq i$;
(11)   If $u_j \ge l_i$ then
(12) $D \leftarrow D - \{j\}$;
(13)   End If;
(14)   End For;
(15) End While;

Algorithm 1

D_0 in the kth iteration). Then, for all $j \le k$, $e_j > u_{i_{k+1}}$. In summary, we have that there is no $e_j \in C_x$ such that $l_{i_{k+1}} \le e_j \le u_{i_{k+1}}$, which is a contradiction. Thus, So for any $i = 1, 2, 3, \ldots, |C_x|$, we have $e_i \ge f_i$. Therefore, assuming that $|C_x| < |C|$, due to $e_1 > f_1, e_2 > f_2, \ldots, e_{|C_x|} > f_{|C_x|}$, we have $f_{|C_x|} = l_{i_{|C_x|}} > u_{i_{|C_x|+1}}$. Consequently, there is no $c \in C_x$ such that $l_{i_{|C_x|+1}} \le c \le u_{i_{|C_x|+1}}$, which is a contradiction. Thus $|C_x| \ge |C|$. The claim holds. And since the spectrum bandwidth occupied by the channel is monotonous, we have $\omega(e_1) \ge \omega(f_1), \omega(e_2) \ge \omega(f_2), \ldots, \omega(e_{|C|}) \ge \omega(f_{|C|})$, and then $\sum_{i=1}^{C_x} \omega(e_i) \ge \sum_{i=1}^{C} \omega(e_i) \ge \sum_{i=1}^{C_x} \omega(f_i)$. So the algorithm outputs the optimal control channels C with the minimum spectrum width when it terminates.

At each iteration of Steps (1)–(5) in the algorithm, for each wireless network node, there are $(n - 1)$ times comparison. So there are a total of $n(n - 1)$ times.

Obviously, the number of iterations in Step (7) is not more than n. And it takes $O(n)$ time to find $\arg\max_{i \in D}\{u_i\}$ in Step (8) and $O(n)$ time for to find comparison in Steps (10)–(13).

To conclude, the time complexity of the algorithm is $O(n^2)$. This completes the proof. □

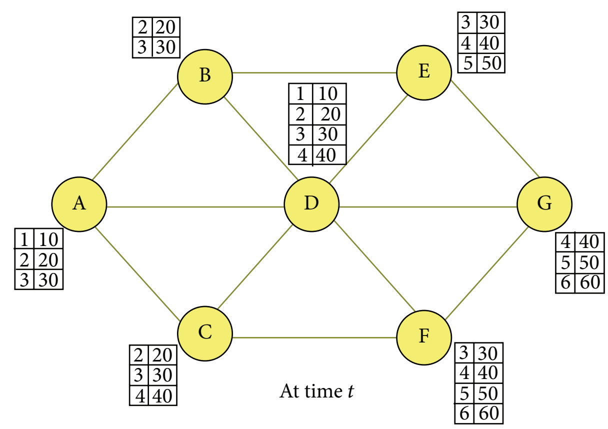

Figure 1: Topology of simulation networks.

5. Evaluation

In this section, we use the numerical simulation method to evaluate the proposed algorithm compared with the proposed algorithm by Zhong [21].

The simulation topology is as shown in Figure 1. The set of available channels of each node at time t is also shown in Figure 1, and the set will change over time. The left column of each table shows the index of each channel, and the right column shows the spectrum bandwidth of each channel. For easy of explanation, we set the total number of available channels to be 6, and index all channels by the ascending order of spectrum bandwidth of each channel, which means that the bigger the index of the channel, bigger the spectrum bandwidth of the channel.

In the simulation, for each run, we use the random number generator to generate the random set of available channels for each node. The simulation executes 60 times of runs in total, sums all simulation results (number of control channels, total spectrum bandwidth of control channels) of each run, and calculates the average values.

Figure 2 shows that number of control channels between our proposed algorithm and Zhong's algorithm is same. The reason behind this result is that these two algorithms use similar method to find the minimum number of control channels. However, Figure 3 shows that there is a big difference of total spectrum bandwidth of control channels between these two algorithms. The results show that our proposed algorithm not only tries to find optimal number of control channels but also reduces the total spectrum.

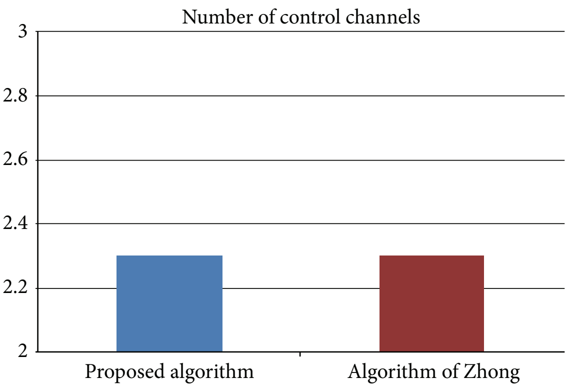

FIGURE 2: Comparison of number of control channels.

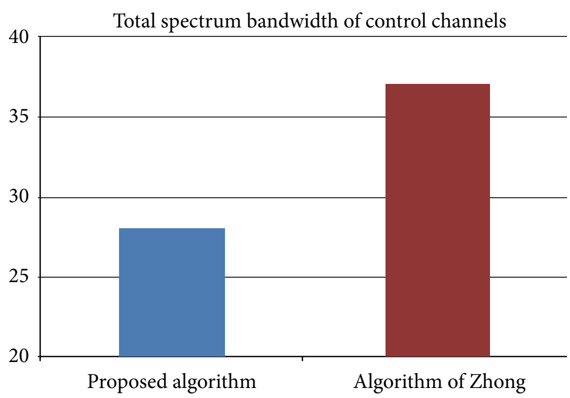

FIGURE 3: Comparison of total spectrum bandwidth of control channels.

6. Concluding Remarks

In this paper, we design an optimal algorithm to find the set of control channels with the minimum spectrum bandwidth for wireless networks. We also present simulation results to show that the proposed algorithm consumes less spectrum resources than Zhong's algorithm in the same wireless network environment. Furthermore, in some other applications, such as spectrum allocation which usually sorts all channels by descending order, the function for spectrum bandwidth of each channel is monotonously decreasing. It is easy to modify the proposed algorithm and obtain similar results for the case.

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