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Research on WLAN Planning Problem Based on Optimization Models and Multi-Agent Algorithm

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***Abstract*—Along with the high quality requirement of wireless communication, the deployment of Wireless Local Area Network(WLAN) has been attracting more and more attention in the field of optimization, with numerous research works investigating the use of formal optimization techniques for WLAN planning. However, when facing the large scale deployment scenarios, these approaches may not effectively optimize them. The main contribution of the work presented in this paper is to describe a mathematical WLAN model and give a multi-agent optimization algorithm which is based on distributed artificial intelligence and has an ability to deploy a large scale WLAN.**

Keywords—WLAN planning; large scale WLAN; WLAN model; multi-agent optimization algorithm

I. INTRODUCTION

WLAN makes its users flexibly connect to networks without physical wires and has become one of the best choices to achieve wireless communication. Although it has a lot of merits such as free frequency band and low cost for building networks, difficult problems with Access Point(AP) deployment still exist because of the finitely allowed frequency range. With the number of APs increasing, the capacity of WLAN coverage will be enhanced, whereas the installation cost of WLAN will rise and its performance might decrease due to a great deal of frequency interferences. The parameter settings of all APs are referred to as a WLAN planning problem[1].

Extensive literature provides all kinds of methods so as to solve the problem mentioned above, while the following might be the typical ones. In E. Amaldi's study[2], a kind of quadratic programming was proposed, but it is only suitable for small WLAN design instances. Some research works consider meta-heuristics algorithms such as genetic algorithm(GA)[3] and the hybrid Tabu Variable Neighbourhood Search Algorithm (TVNS)[4], because this problem is NP-Hard combination optimization problem mathematically to which meta-heuristics method is normally applied. However, unlike meta-heuristics algorithms used in outdoor wire communication[5],[6],[7], optimizing an indoor WLAN problem is obliged to consider the nature of indoor environment that is very complex because of signal interference and attenuation caused by walls, floors, furniture, and other objects, which makes solution space complicated and may result in failure to obtain near-optimal solution for the searches of the optimization algorithms.

The indoor WLAN planning problem with complicated solution space compels an optimization process to be combined well with the background of WLAN for high efficiency in search. To achieve efficient search process that can be successfully utilized to solve this kind of problem, a multi-agent optimization algorithm will be designed in this paper. Multi-agent system consists of a group of agents that collectively perform collaborative tasks, which can be applied to tackle the problems in different circumstances. The feasibility of technology about multi-agent optimization has been proved in some researches, for example, sensor networks[8],[9], microgrid[10] as well as quadratic assignment problem[11].

The rest of the paper is organized as follows. In the next section the problem definition of WLAN planning is described and the indicator which are used to evaluate network throughput is given. Section 3 describes the the design of multi-agent system and presents the pseudo code about multi-agent optimization algorithm. The experiments and results are given in section 4. Final section gives the conclusion and perspective of this paper.

II. MODELING WLAN PROBLEM AND EVALUATION INDICATOR

The modeling process of WLAN system is based on a mathematical description of Quality of Service (QoS). Some WLAN planning models are worth learning from related works [12],[13],[14]. To evaluate the quality of network configuration, the definition of an indicator about QoS is crucial. In proposed model, the calculation area is divided into a grid of pixels. The pixel center is called a Marking Point (MP), and a Test Point(TP) is defined as the MP which is occupied by people in need of rate requirement. The defined indicator is calculated in service zone in order to estimate the performance of network configuration.

A. Modeling WLAN Problem

1) AP Model

In this model, candidate site locations and AP settings containing AP location, AP frequency, AP azimuth and AP power are defined. The candidate site locations are defined by a

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vector of n items $S=(s_1,\ldots,s_i,\ldots,s_n)$. Here, each item s represents a candidate site. The AP settings are characterized by the following configuration parameters (s,a,p,h,f).Here, s is denoted by the candidate site where the AP is installed, a is the type of AP used, p is the emitted power, h is the azimuth and f is the channel. Thus, the solution of problem can be expressed by the configurations of a set of APs in the whole building.

2) Radio Signal Model

To achieve communication service, a user terminal should receive enough signal strength from at least an AP. The RSS expression and minimum RSS which can be perceived by a user terminal are defined in the radio signal model. Here, with the AP characteristic (s,a,p,h,f), the RSS expression at a MP m is expressed by $rss_{sm}=\chi(m,s,a,p,h,f)$. Here, $\chi(.)$ is a function related to the indoor propagation model and the units are in *dBm*.

3) Throughput model

In this model, the main task is to acquire the real bit rate offered to the users. Signal-to-Interference-plus-Noise-Ratio (SINR) determines the user's nominal bit rate which is bigger than user's real bit due to some extra overheads such as protocol overhead. If SINR is smaller than SINR threshold, the user will not gain normal communication service. When nominal bit rate and MAC scheme are determined, the total throughput provided by an AP can be calculated. The relevant computation method can be found in relevant works [4], [15].

Here, some mathematical definitions are described as follows: the number of users in TP t is denoted by n_t^u; the real bit for a user who needs communication requirement in TP t is denoted by r_u^t; r_t^T represents the total throughput provided by an AP which offers communication service to all users in TP t. In this paper, it is assumed that channel access is shared equitably among the clients. In other words, an AP sends the same number of frames to all its customers. Then, the real bit for a user in TP t is expressed by $r_u^t=r_t^T/n_t^u$.

B. Evaluation Indicator

The ultimate aim of WLAN design is to satisfy the bit rate requirements of users in communication zone as far as possible. The objective of WLAN planning can be described as follows mathematically:

$$\text{To minimize}:\ obj=\sum_{t\in T_c} max(n_t^u \times r^u - r_t^T, 0) \tag{1}$$

Here, r^u represents the bit rate required by one user, and the set of Test Points in service zone is denoted by T_c. *obj* is an indicator to evaluate QoS of current WLAN configuration. Obviously, the smaller *obj* is, the better WLAN plans. Furthermore, if there exist two WLAN configurations and their QoS indicators are the same, then their AP numbers will be compared. Between them, the WLAN configuration with less number of APs has higher evaluation for its saving cost of AP installation. Hence, the QoS indicator in WLAN deployment should firstly be taken into consideration, and the number of APs is only a secondary consideration.

III. MULTI-AGENT OPTIMIZATION ALGORITHM

In multi-agent optimization algorithm, an AP is regarded as an agent, as well as all APs in communication zone make up a distributed multi-agent system. On the one hand, an agent can perceive its environment and take reasonable actions to improve the QoS of local environment; on the other hand, the system can globally control the number of agents to strengthen the optimizing capability and avoid premature convergence.

A. Agent Percepts

Agent percepts are the premise of an agent making logical decision as its performance heavily relies on current environmental status. The agent percepts involve its position, channel, azimuth, emitted power and utility function.

1) Position, channel, azimuth, emitted power

These four parameters are agent's important configurations that have an impact on QoS for WLAN deployment. Position is one of the candidate sites, and an agent can leave original position to move to another empty candidate site. In the same frequency band, change of the channel only alter frequency relationship among agents, which does not influence the field strength distribution. Similarly, azimuth and emitted power only have impact on the the field strength distribution around agents.

2) Utility function

The goal of an agent is to maximize the bit rate provided to users who connect to it for communication service. For the i^{th} agent, its utility function can be expressed as the sum of the bit rate that offered by it:

$$u_i = \sum_{t\in T_{agent_i}} n_t^u \times \min(r^u, r_u^t) \tag{2}$$

Here, u_i is a utility function of the i^{th} agent. T_{agent_i} represents the set of the TPs connecting to the i^{th} agent.

B. Local Control

The local control is that one agent takes actions to improve the communication quality, which optimizes the problem from the view of an agent. Good behavior of an agent can lead the search to the good direction in solution space.

1) Action rules

The search direction of algorithm in solution space depends on actions of agents. Therefore, it is necessary to design action strategy combined with some knowledge of WLAN communication.

When an agent changes its channel, only the relationship of frequencies around it will change, which has no impact on the relationship of field strength in any place. However, an agent who moves to other new position not only influences the communication coverage in the original position, but also gives rise to new frequency interference in the new position. The strategy of only move is unwise for an agent, so it is necessary to perform frequency operation after moving to a new place in order to cut down the frequency interference. By this way, the bad direction of search will be avoided even if the solution space is very complicated. In this paper, the compound action for moving and frequency operation is deemed to one action.

Because both azimuth and emitted power of an agent only impact the relationship of field strength around it, these two parameters can be combined. Besides, to add the rationality of behavior, the channel operation will be carried out after taking the integrated adjustment of azimuth and emitted power. So, the compound action of azimuth adjusting, changing power and frequency operation is also regarded as one action in this paper.

2) Cooperative game

Once an agent takes an action, it will maximize its own utility, which may do harm to entire group of agents. Concerning too much about individual utility makes search fall into local optima fast. For high quality behaviors, the tool of cooperative game [16] is utilized. In cooperative game, at each turn, only one agent can take one action. The next agent cannot take any action until the last agent ends the game. What's more, to ensure good QoS of WLAN, actions of an agent will be limited until it forecasts that the QoS will be better after taking an action. An action which leads to worse QoS is regarded as an irrational behavior, so this bad action must be restricted.

C. Global Control

In multi-agent system, an agent has no ability of global control without which the algorithm is hard to jump out of local optima, but the system itself can control the number of agents globally to increase the range of search in solution space. The global control includes adding an agent and deleting an agent.

1)Adding an agent

The total output of the current agent group is finite and the covering capacity of an agent is also limited, which drives system to generate a new agent. When all actions of agents are restricted in cooperative game, the temporary agent may be created. The azimuth and emitted power of temporary agent is randomly generated. The temporary agent attempts to find the best combination of channel and position for its maximal utility. After finding this combination, the QoS for current WLAN deployment will be forecasted. If the predicted QoS is declined, the temporary agent will seek the new combination of channel and position which only can promote QoS. Once both old and new predicted QoS are worse, the temporary agent will disappear. Otherwise, the temporary agent can join into the system.

2)Deleting an agent

Once meeting sophisticated solution space, the algorithm should be qualified to adjust by itself to make the search towards the good solution in solution space. When all agents' actions are limited, the system will seek the redundant agents who bring more harms than benefits. The system only deletes the agent with the worst performance among the redundant agents. If this agent is successfully deleted, the generation of new agent will not be taken into consideration temporarily.

D. Algorithm Pseudo-Code

Multi-agent optimization algorithm consists of two parts. One describes cooperative game among agents. Another part is global control, which is an adjusting way of the system and lead the search direction to another part of the solution space.

With no special instructions, the termination of the algorithm is that the current system cannot possibly add a new agent any more or the QoS indicator mentioned in section 2 is equal to 0. Some notations and definitions are as follows.

— The set of agents in current multi-agent system is denoted by $Agent=\{agent_0\ ,\ agent_1\ \ldots agent_i\ \ldots\ agent_{n_{agent}-1}\}$. Here, $agent_i$ represents the i^{th} agent in multi-agent system, n_{agent} is the total number of agents in current system.

—For $agent_i$, f_i^{agent}, h_i^{agent}, p_i^{agent}, s_i^{agent} represent its frequency parameter, azimuth parameter, emitted power parameter and position parameter, respectively.

—The sets of the available frequencies, emitted powers, and azimuths which an agent can gain are denoted by F,P,H, respectively.

—The set of candidate sites unoccupied by APs is denoted by S^e. Obviously, S^e is a dynamic set and varies from one deployment of APs to another.

—$agent^{temp}$ represents temporary agent, and its frequency parameter, azimuth parameter, emitted power parameter and position parameter are denoted by f^{temp}, h^{temp}, p^{temp}, s^{temp}, respectively.

— $u_{temp}(s,f)$ represents the utility value of temporary agent when its position is s and frequency is f.

—$U_i(\cdot)$ represents the utility value of $agent_i$ which is under the condition that it takes one action: "$\cdot$" is f when it adjusts the frequency to f ; if it takes the compound action of moving to empty candidate site s and adjusting the frequency to f , "$\cdot$" is (s,f); when $agent_i$ takes the compound action of adjusting the azimuth, power and frequency to h,p,f, respectively, "$\cdot$" is (h,p,f).

— n_{no_action} represents the iteration times of multi-agent system continuously remaining changeless, which will be equal to zero if one agent does an action successfully or the system succeeds in global control.

—$Pre(i\ ,\ \cdot)$ represents the predicted value of QoS before the i^{th} agent making an action. Here, "$\cdot$" is the type of actions: "$\cdot$" is f or (s,f) or (h,p,f) when it adjusts the frequency to f or adjusts the position to s and the frequency to f or adjusts the azimuth to h, the power to p and the frequency to f.

—$Pre(delete,\ k)$ and $Pre(add,(s,f))$ represent the predicted value of QoS before system deleting the k^{th} agent and the predicted value of QoS before system adding an agent whose position is s and frequency is f, respectively.

—For $agent_i$, the action to achieve the optimal frequency is defined by *Only_Channel*(i); *Azimuth_Power_Channel*(i) is to get the most suitable combination of azimuth, emitted power and frequency; the best comprehensive action of moving as well as adjusting the frequency is defined by *Move_Channel*(i). The pseudo codes of these operations are shown below:

Function1:*Only_Channel*(i)

1. $f_{max}=\{f|\max\{U_i(f)\},f\in F\backslash\{f_i^{agent}\}\}$
2. m=0
3. **If** $U_i(f_{max}) > u_i$ and $Pre(i, f_{max})<obj$
4. $f_i^{agent}=f_{max}$
5. n_{no_action}=0, m=1
6. **End if**

Function2: *Azimuth_Power_Channel*(i)

1. $(h_{max},p_{max},f_{max}) =\{(h,p,f)|\max\{U_i(h,p,f)\},h\in H\backslash\{h_i^{agent}\},p\in P\backslash\{p_i^{agent}\},f\in F\backslash\{f_i^{agent}\}\}$
2. m=0
3. **If** $U_i(h_{max},p_{max},f_{max}) > u_i$
4. **If** $Pre(i, (h_{max},p_{max},f_{max}))<obj$
5. $h_i^{agent}=h_{max}$, $p_i^{agent}=p_{max}$, $f_i^{agent}=f_{max}$
6. n_{no_action}=0, m=1
7. **End if**
8. **End if**

Function3:*Move_Channel*(i)

1. $(s_{max},f_{max})=\{(s,f)|\max\{U_i(s,f)\},f\in F\backslash\{f_i^{agent}\},s\in S^e\}$
2. m=0
3. **If** $U_i(s_{max},f_{max}) > u_i$
4. **If** $Pre(i, (s_{max},f_{max}))<obj$
5. $s_i^{agent}=s_{max}$, $f_i^{agent}=f_{max}$
6. n_{no_action}=0, m=1
7. **End if**
8. **End if**

As *Move_Channel* is the most time consuming action and has the greatest impact on relationship of the field strength, this action is finally considered. *Only_Channel* is the top priority action because it does not change the relationship of field strength among agents and spends the least consuming time. The multi-agent optimization algorithm is as following:

Algorithm1: multi-agent optimization algorithm

1. Randomly initialize $agent_0$
2. n_{agent}=1, n_{no_action}=0, i=0
3. **While** the stop condition is not met
4. *Only_Channel*(i)
5. **If** m is equal to 0
6. *Azimuth_Power_Channel* (i)
7. **End if**
8. **If** m is equal to 0
9. *Move_Channel* (i)
10. **End if**
11. **If** m is equal to 0
12. n_{no_action}++
13. **End if**
14. $i=(i+1) \bmod n_{agent}$
15. **If** $n_{no\_action}\geq n_{agent}$
16. Apply the global control algorithm
17. **End if**
18. **End while**
19. **Return** *Agent*

Algorithm2: Global control algorithm

1. $k_{min}=\{k|\min\{Pre\ (delete, k)\}, k=1,2\ldots n_{agent}-1\}$
2. **If** $Pre\ (delete, k_{min})< obj$
3. $Agent= Agent\backslash\{agent_{k_{min}}\}$
4. n_{no_action}=0, i=0, $n_{agent}=n_{agent}-1$, m=1
5. **End if**
6. **If** m is equal to 0
7. Randomly generate h^{temp},p^{temp} for $agent^{temp}$
8. $(s_{max},f_{max}) =\{(s,f)|\max\{u_{temp}(s,f)\},s\in S^e, f\in F\}$
9. **If** $Pre(add,(s_{max},f_{max}))< obj$
10. $s^{temp}= s_{max}$, $f^{temp}=f_{max}$
11. $Agent= Agent\cup\{agent^{temp}\}$
12. n_{no_action}=0, i=0, $n_{agent}=n_{agent}+1$, m=1
13. **End if**
14. **End if**
15. **If** m is equal to 0
16. $(s_{max},f_{max})= \{(s,f)|\min\{Pre(add, (s,f))\}, s\in S^e, f\in F\}$
17. **If** $Pre(add,(s_{max},f_{max}))< obj$
18. $s^{temp}= s_{max}$, $f^{temp}=f_{max}$
19. $Agent= Agent\cup\{agent^{temp}\}$
20. n_{no_action}=0, i=0, $n_{agent}=n_{agent}+1$
21. **End if**
22. **End if**

IV. Experiment and Result Analysis

A. Experimental Environment

To evaluate the practicability of multi-agent optimization method, the test bed of the large scale scenario(Fig.1) with a two-floor building was selected.

Fig. 1. The large scale experimental scene

Each floor size is 120m x 40m (4800 MPs at each floor), and a total of 94 candidate sites are defined for AP installation: 54 candidate sites at first floor and 40 candidate sites at second floor. AP parameter settings are 1 type of AP with a unidirectional pattern, 1 type of power and 13 available frequencies under the 802.11b standard. For the service zone, 200 users are uniformly distributed on each service zone (each floor) and each user demand is about 500 kbps real bit rate. Consequently, the global demand for the whole building is 200000 kbps.

B. *Comparisons of Two Algorithms*

In order to evaluate the performance of our algorithm, comparisons between our algorithm and TVNS[4] algorithm are presented. The initial solution of TVNS algorithm is vital, which is generated by greedy randomized adaptive search procedure(GRASP)[17] and iterative local search.

The results of these two algorithms are compared from two aspects. One is the best-run results from two algorithms at different CPU times, which are illustrated in Fig.2. Another is the best QoS indicators that can be found in different cases of not exceeding a certain number of AP before both the algorithms converge, which are shown at Table 1 and can provide more clear choices for WLAN planner.

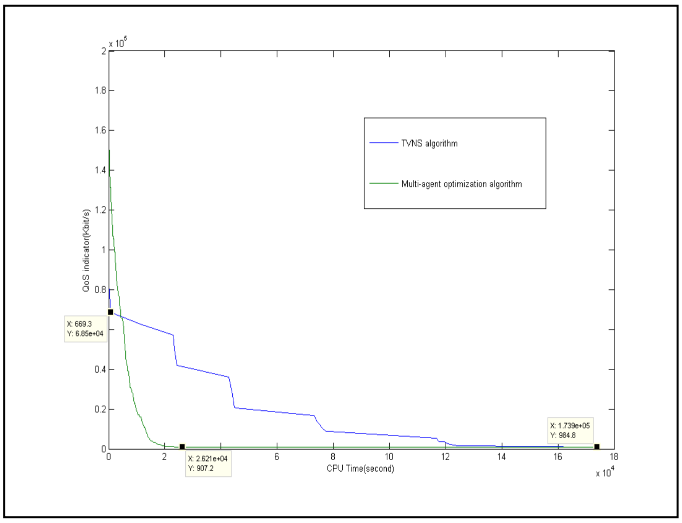

Fig. 2. The best QoS indicators at large scale scene

The curves in Fig. 2 represent the convergences of the best QoS indicators for the large scale WLAN plan. The green one indicates our algorithm. The blue one shows the performance of TVNS algorithm where the generation of initial solution costs 669.3 seconds. The convergence rate for our algorithm is about 6.6 times faster than TVNS algorithm because our algorithm deals with the planning problem from two views: individual view from an agent and global system view. TVNS ignores the interaction and cooperation between different solutions in search process and has only one global view — view of solution attribute, which results in poor efficiency.

TABLE I. THE BEST QOS INDICATOR WITH LIMITED MAX AP NUMBER

Limited max AP number	Best QoS indicator in our algorithm	Best QoS indicator in TVNS algorithm
30	38848 kb/s	48236 kb/s
35	19823 kb/s	31643 kb/s
40	8881 kb/s	16582 kb/s
45	2275 kb/s	13507 kb/s
50	1303 kb/s	3584 kb/s

As can be seen from the Table 1, the best QoS indicator in our algorithm is always smaller than in TVNS algorithm under the same limited max AP number. Apart from that, the best QoS indicator in TVNS algorithm is not less than 10000 kb/s until the limited max AP number reaches 50, while the best QoS indicator in our algorithm has attained 8881 kb/s in the situation that the limited max AP number is only 40.

The directions of searches of these two optimization algorithms depend heavily on information of previous search in the large scale and complicated WLAN planning problem. In our algorithm, through the tool of cooperative game, each AP is in a friendly communication environment where the frequency interferences are low and the total throughput from an AP verges on its maximum output of device at first, which can help the future searching direction enter into the parts of good solution in solution space. But TVNS algorithm has no method to make each AP in this kind of good environment. Due to the complex solution space, it is difficult for TVNS to find a series of coherent amounts of information that can lead searching direction to the parts of good solution in solution space. Therefore, our algorithm can handle the large scale WLAN deployment problem better.

V. CONCLUSION AND PERSPECTIVE

In this paper, some optimization techniques about WLAN design were investigated in previous work and the multi-agent optimization algorithm is proposed to solve the large scale WLAN planning project. For the large scale WLAN design problem, the density and distribution of good solutions in solution space are low and inhomogeneous, respectively, which demands that the algorithm needs to have a strong capability for optimizing. The results in experiment show that our algorithm has higher search efficiency than TVNS. Our algorithm synthetically considers the relationship of channels and field strength, which can increase the diversity of search trajectory. Moreover, the global control from multi-agent system can help the search jump out of local optimum.

However, with the number of candidate sites largely increasing, one agent can gain plenty of opportunities to adjust its position very slightly, weakening the integrated relationship between frequency and field strength, which may result in redundant search and increasing the run time of algorithm because there is no need to always adjust frequency after moving. Therefore, how to develop more rational action strategies and balance the relationships among AP position, frequency, azimuth and emitted power at different parts of solution space in the optimization process for accelerating the running speed of algorithm are our future work.

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