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Implementation of Wireless Sensor Networks in WLAN Systems for Cooperative Spectrum Sensing

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Abstract

To solve the problem of throughput decrease caused by spectrum interference in Wireless Local Area Networks (WLAN), this paper proposes a network model based on Wireless Sensor Network (WSN) for cooperative spectrum sensing. The model takes advantage of WSN's features of distributed computing and system synthesis to determine the channel combination with less spectrum interference, hence improves the system throughput. Furthermore, key technologies have been designed for practical applications, including the nodes communication procedure between the access point (AP) of WLAN and the sensor nodes of WSN, the algorithms of selecting channels with less spectrum interference and the strategy of adapting the network on the best channel combination. Test results of verification platform based on a typical high-density indoor coverage scenario show that: 1) The sensing ability of the proposed network model is better than that of single AP sensing; 2) Compared with traditional WLAN without sensing ability or WLAN based on AP sensing, the throughput of the proposed network model can be raised by 66% or 38%.

***Keywords**: Sensor networks; WLAN; Cooperative spectrum sensing*

1. Introduction

Wireless Local Area Networks (WLAN) was started by Institute of Electrical and Electronic Engineers (IEEE) in standard of 802.11 in 1990s, and after that a series of access technologies grew up, like 802.11a/b/g/n/ac etc. The WLAN standard operates on the 2.4 GHz and 5 GHz Industrial, Science and Medical (ISM) frequency bands. Since these frequency bands are unlicensed and free of charge, WLAN technology becomes the leading and commonly used network access technology, and almost all user mobile devices possess Wi-Fi access capability, including smart phone, tablet PC and laptop. As the ISM frequency bands is also used by other wireless infrastructures, such as Zigbee networks, microwave oven, Bluetooth device, medical instrument etc., so coexisting with these systems would bring external interference to WLAN. In addition, due to lack of unified radio resource management, interferences between WLAN access points (APs) exist when different APs choose the same or adjacent frequency band. Therefore, the internal and external system interference has become one of the main problems in WLAN deployment.

Current solutions for solving this problem can be classified into two major categories. The first one is to extend WLAN system in new spectrum, where interference is not so fierce; the second one is to improve AP's spectrum sensing ability, making it select best working channel adaptively. For new spectrum bands, 5GHz frequency band is introduced in 802.11a in 2000 [1]. 3.65GHz and 3.7GHZ frequency band are introduced in 802.11y in 2012. Recently, Europe Union and U.S.A are calling on 2.6GHz and 3.5GHz channels being applied to WLAN as well. However, as more users choose WLAN and new frequency bands are also unlicensed, and in 802.11ac even single user needs for 80MHz bandwidth, so extending new spectrum cannot fully resolve this problem. Therefore,

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many researches have been done to equip the WLAN system with spectrum sensing ability, which will help the WLAN APs to choose a working channel with less inter- or intra-system interference. In 802.11y, Dynamic Frequency Selection (DFS) is introduced as the enforced mechanism of WLAN operated on 5GHz channel, to avoid the interference from military radar system [3], which requires APs to possess spectrum sensing ability, so that APs can dynamically select channel with less interference for communication. However, DFS is limited by 5GHz channel, while WLAN is mainly deployed on 2.4GHz nowadays, which has no compulsive requirement on it. So in [5], APs are designed to have the sensing ability on both 5GHz and 2.4GHz frequency bands, and APs can measure on adjacent APs to acquire the mutual interference level. Based on graph coloring theory, each AP can select a cleaner channel, so as to improve the network throughput. But the problem is AP's real-time measurement is not favorable because it cannot adjust in time when wireless environment changes, and the measurement would suspend the normal data transmission. Thus, [6] has proposed a channel overlap model for channels interference measurement, which has taken both co-frequency and adjacent frequency into consideration to get a better channel allocation. However, the measurement result still cannot truly reflect the downlink interference within AP coverage area and cannot sense hidden node interference, so network still cannot get the best performance, and more researches are necessary to overcome these practical drawbacks.

In this paper, we introduce Wireless Sensor Networks (WSN) into WLAN system, taking advantage of its distributed computing and system synthesis ability to improve WLAN's sensing ability. Different from traditional networks which is data transmission oriented, WSN are application oriented and can complete sensing, assembling and processing for its interested target or incident through the collaboration of plenty of random sensory nodes. Thus the WLAN system has more comprehensive perspectives on radio interference in both uplink and downlink. Co-working with WLAN for cooperative spectrum sensing, WLAN APs can get the spectrum sensing results simultaneously and more accurately, their ability on anti-interference is enhanced, hence the system throughput is improved. The rest of the paper is organized as follows: Section II proposes and defines the WLAN system model based on WSN. Section III provides the theoretical analysis for key technologies of the proposed network model, and the engineering problem in deployment is also discussed. In Section IV, an experimental environment is established to verify the advantage of the proposed model. Section V concludes the paper.

2. System Model Overview

Conventional sensor network includes four entities: sense target, sense scenario, sensor node and sink node. Sensor network is application oriented, and when applied in WLAN, each entity is endowed with special meaning. Among them, sense target represents the interference level of WLAN's 2.4GHz and 5GHz channels. Sense scenario is the coverage of a group of WLAN APs. Sensor node is the basis of the whole sensor network, which is randomly scattered in sense scenario of high density, and each sensor node processes an ability of sensing WLAN frequency bands. Sink node works as the bridge between sensor network and applications. And we choose WLAN APs and UEs in sense scenarios as sink node, which can communicate with sensor node to acquire sense information, and assemble the sensing result as the input of the best channel selection [4]. On the other hand, APs and UEs usually themselves process sensing ability and are regarded as sensor node in some specific circumstances. In addition, UE is often mobile terminal and so it belongs to the category of mobile sink. And benefits from the mobility, sink node can gather the sense result of the sensor nodes near to the track of the moving positively. So the unbalance loading of the sensor nodes and the invalid of isolated sensors can be solved, especially in the asymmetric distribution scenarios. Besides, energy consumption due to multi-hoping routing can be avoided, so that sensor nodes' lifetime is greatly extended [8].

Figure 1 describes on a WLAN system based on thin AP architecture, in which AP's working channel, transmit power level and other configuration parameters are decided by AP Controller (AC), and groups of APs consist of a continuous coverage to supply the data service to the User Equipment (UE), whilst a WSN is also deployed within the coverage area. There are numbers of sensor nodes distributed randomly in higher density than that of APs, which could sense the working frequency bands of WLAN and report the sensing result to the sink node nearby. Here, a cooperative spectrum sensing scheme is adopted, sink node (AP) can sense the radio environment more accurately. Then, in order to get the best network performance, all the sensing result should be collected and synthesized on AC, where the least interference channel combination is achieved by using graph coloring algorithm and rational network optimization strategy to adjust channel combination. Several kinds of key technologies of our proposed mode, namely cooperative spectrum sensing, node communication process and network optimization strategy, will be described in the next section in details, and theoretical and practical issues will also be discussed to enable the model to be a deployable system.

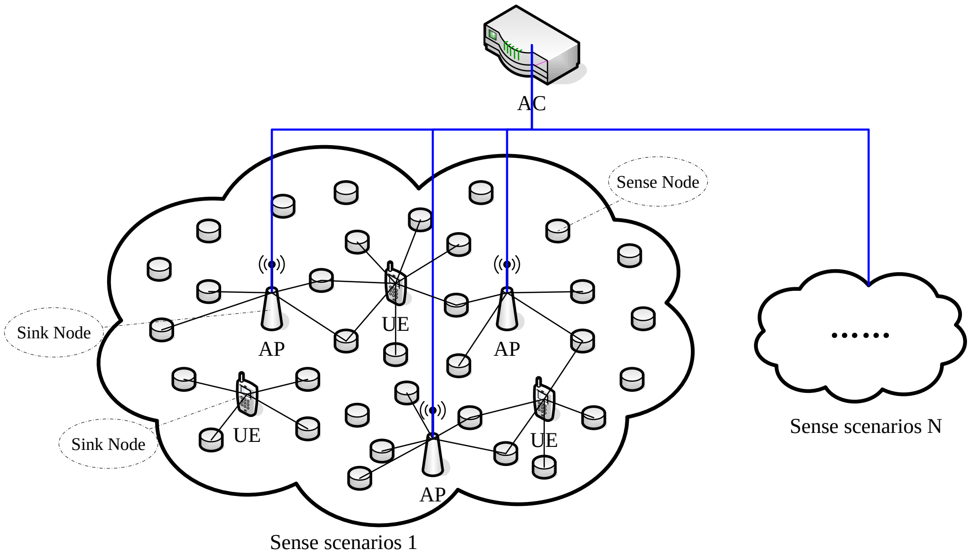

Figure 1. System Model of WLAN Based on WSN for Cooperative Spectrum Sensing

3. Key Technology

3.1. Cooperative Spectrum Sensing

Sensor node is the basis of WSN. Common sensing methods include: energy detection, matched filtering and feature extraction. The latter two must be based on some priori knowledge of interference signal, because they are complicated in algorithm and not universal although their detection sensitivity is higher. And considering about node's volume and power consumption, sensor nodes in this paper all adopt energy detection algorithm [9].

For single sensor node, spectrum sensing can be simplified as a binary detection event:

$$x(t) = \begin{cases} n(t) & H_0 \\ h * s(t) + n(t) & H_1 \end{cases} \tag{1}$$

In Formula (1), $x(t)$ represents signals received by sensor node, $s(t)$ is transmitter's sending signal, $n(t)$ is addictive white Gaussian noise, h is channel impulse response. Event H_0 represents frequency band is free, and H_1 means frequency band being occupied.

Detector, based on frequency band energy, enjoys detecting sensitivity depending on how complicated signal process algorithm is. The more complicated the algorithm is, the longer the detection duration is. So it is considered that detection sensitivity is related to duration. Suppose sensing duration is integer *m*, and the output Y from sensor node is the input of energy decision, so the output Y can be simplified as being subjected to the following distribution [10]:

$$Y \sim \begin{cases} \chi^2_{2m}, & H_0 \\ \chi^2_{2m}(2m\gamma), & H_1 \end{cases} \tag{2}$$

In Formula (2), χ^2_{2m} and $\chi^2_{2m}(2m\gamma)$ respectively represents the chi-squared distribution of centre and non-centre, their degree of freedom are both 2m, γ is mean value of fading signal SNR, which is determined by transmitting power and path loss.

As for non-fading scenario, spectrum acquisition probability P_d totally depends on channel impulse response h:

$$P_d = P\{Y > \lambda \mid H_1\} = Q_m(\sqrt{2m\lambda}, \sqrt{\lambda}) \tag{3}$$

In Formula (3), λ represents energy detector's decision threshold, Q_m is Macrum Q function and definition as [11]:

$$Q_m(a,b) = \int_b^\infty \frac{x^m}{a^{m-1}} e^{-\frac{x^2+a^2}{2}} I_{m-1}(ax)dx \tag{4}$$

Here $I_{m-1}(ax)$ represents amendatory Bessel function, and rank is m-1.

As for Rayleigh fading channel, channel impulse response h changes with fading, and now acquisition probability P_d can be:

$$P_d = \int_x Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) f_\gamma(x)dx \tag{5}$$

In Formula (5), $f_\gamma(x)$ represents probability density function reflects SNR changing in fading condition. In Rayleigh fading, γ subjects to exponential distribution, and by replacing $f_\gamma(x)$, P_d can be approximately represented as:

$$P_d = \frac{\Gamma(m-1, \frac{\lambda}{2})}{\Gamma(m-1)} + e^{-\frac{\lambda}{2(1+m\gamma)}}(1+\frac{1}{m\lambda})^{m-1} \times \left[1 - \frac{\Gamma(m-1, \frac{\lambda m\gamma}{2(1+m\gamma)})}{\Gamma(m-1)}\right] \tag{6}$$

Suppose that each node's spectrum sensing result is independent and identically distributed, so the best combination rule is K rank rule, that is to say, among n nodes, if more than k nodes are predicated to be H_1, then frequency band is considered to be occupied. With guidance of K rank rule, detection probability Q_d and false alarm probability Q_f of joint spectrum sensing can be represented as:

$$Q_d = 1 - (1 - P_d)^n \quad (7)$$

$$Q_f = 1 - (1 - P_f)^n \quad (8)$$

In Equation (7) and (8), n is the number of the nodes participated in cooperative sensing. Compared with single node sensing, using the same decision threshold, cooperative spectrum sensing can effectively increase detection probability and reduce false alarm probability without increase node algorithm complexity. That is the superiority of the WSN.

Furthermore, as for WLAN system, cooperative spectrum sensing is also helpful for solving of the hidden node's problem [12], as showed in Figure 2.

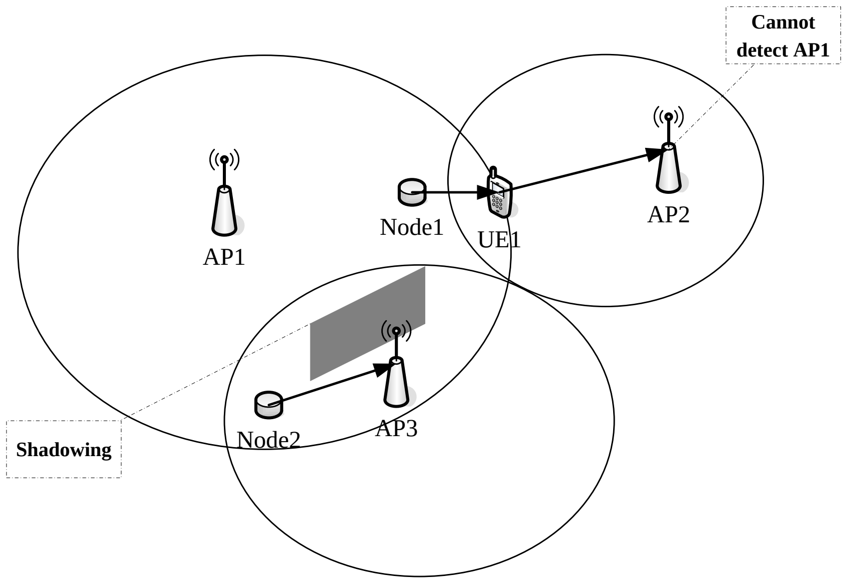

Figure 2. Hidden Node: A) Receiver Uncertainty and B) Shadowing Uncertainty

Scenario a: UE1 lies in overlapping area of AP1 and AP2. There would be serious intra-system interference if AP1 and AP2 choose the same working channel once they cannot sense each other; Scenario b: AP3 should have sensed AP1, but it failed as a result of shadow effect. These are two typical hidden node problems. However, if there are sensor nodes like Node1 and Node2 inside system, the hidden node problem can be effectively resolved. For instance, Node1 would report its sensing result of AP1 to UE1, and make AP2 sense AP1 by means of sensing result sharing; and Node2 lies outside the shadow, so it can sense AP1 and report the result to AP3. In real deployment, the distribution density of sensor node is far larger than that of AP distribution, and UE is also a kind of mobile sink, so the hidden node problem can be well solved.

3.2. Nodes Communication Procedure

Power saving of sensor node and cooperative gaining of sink node needs to be taken into consideration in the designing of communication procedure between sensor nodes and sink node. The communication procedure is an aspect of MAC layer, and the main purpose of typical WSN's MAC layer is to reduce redundancy monitoring for saving power by means of shutting down radio modules of sensor node as possible. Moreover, it is premised that WSN can withstand a certain extent of communication delay [13]. While in WLAN system, requirement on communication delay is higher because spectrum sensing information should be knew in real time [14]. So the duration of sensing request and report collection should be long enough to make sure all the nearby sensor nodes can catch it and response. Meanwhile, the feedback of sensing result should be short enough to save nodes' power and avoid collision and interference among nodes. Figure 3 has described the procedure in details. In Figure 3, T_w represents wake period of sensor node, T_r represents report period of sense result, T_0 represents detecting period of sink node, T_2 represents sense result assembling period of sink node.

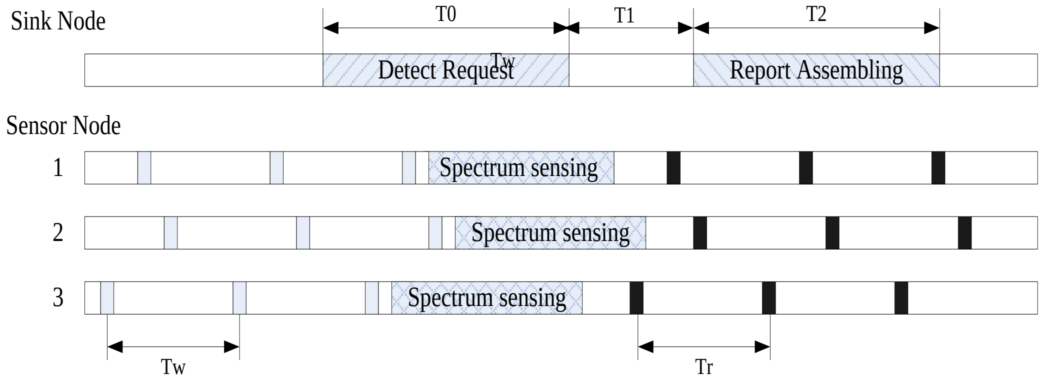

Figure 3. Communication Process between Sink Node and Sensor Node

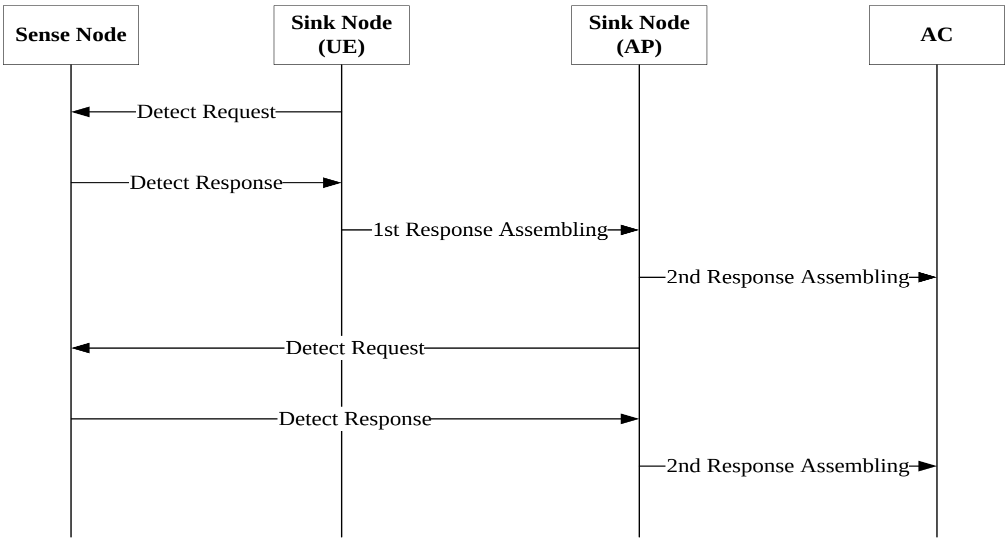

Figure 4. Signal Procedure between Sensor Node and UE, AP and AC

Figure 4 depicts the processing procedure of sensor nodes. Step1: Sensor node is set to be in semi-asleep mode, T_w is wake period, to detect if there is detecting request; Step2: Sink node triggers detecting request periodically, the period is T_0; Step3: Sensor node gets detecting request and makes sure that it does not start spectrum sensing within given period (avoid wasting power by repeating sensing), then start Wi-Fi working channel spectrum sensing immediately; Step4: After spectrum sensing is done, sensor node starts sensing result reporting by period of Tr, and after reporting for three times, it enters semi-asleep mode again and caches spectrum sensing result; Step5: Sink node starts sensing result assembling in T1 after detecting request sending; Step6: Sink node reports all sensing results assembled within T_s to WLAN AC.

Especially, there are two times of assembling. The first one is that sink nodes (AP) gather the sensing report from sink nodes (UE), and the second one is AC collect the reports from sink nodes (AP). So AC can assemble all the usable sensing report in the WLAN working area, then the whole spectrum interference view in the coverage can be reconstructed.

3.3. Network Optimization

After assembling two sensing results, WLAN AC has acquired full view of network interference condition. But in order to achieve a better performance, the best channel selection algorithm and network optimization strategy is needed.

① The best channel selection algorithm

AP's best channel selection can be considered as the coloring problem in graph theory [15], similar to four colors conjecture，only four colors can be used for any area on a plane or sphere, and no adjacent areas are in the same color. Channel allocation principle tries to make neighbor APs adopt different channels, and then the sum of "weight" which connects APs is the minimum, as showed in Figure 5. So that total interference is the lowest. Here the weight represents the interference between two APs, which is decided by the distance of the two APs in both geography location and working frequency.

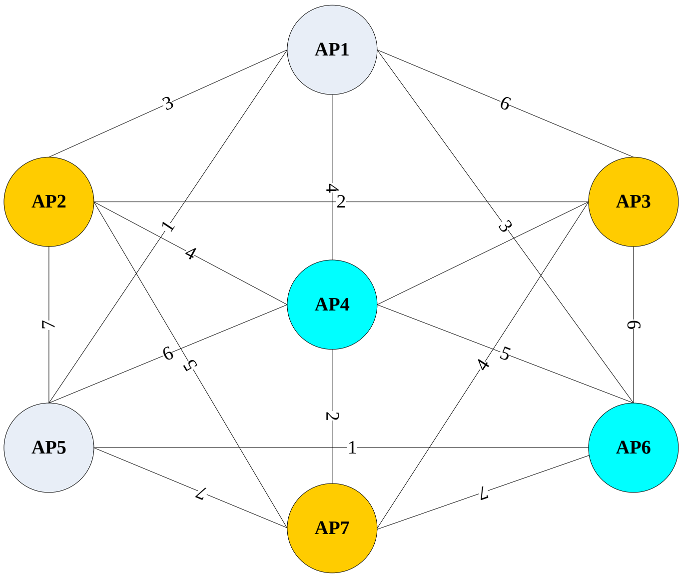

Figure 5. Graph Coloring Problem

To solve the graph coloring problem, annealing algorithm is usually adopted. Define i=1,2,..…,N; N is the number of AP in network; j=1,2,......,M; M is the number of valid channel; k=0,1,2,……,K; K is the number of sink nodes (UE)under single sink nodes (AP), when k=0, sink node is AP itself; l=1,2,……,L; L is the number of sensor node under single sink.

According to definition in 3.2, sensor node can report sensing result--RSSI to sink node; Define $RSSI_{k,l}$={$rssi_1$, $rssi_2$,……, $rssi_M$}. Define that N*M matrix D represents downlink interference level, which is calculated by sensing result assembled by UE, the element d_{ij} in matrix represents the downlink interference level in channel j within the coverage of the i^{th} AP, and the unit is dBm:

$$d_{ij} = \frac{1}{K+L}\sum_{k=1}^{K}\sum_{l=1}^{L} RSSI_{k,l} \qquad (9)$$

Define that N*M matrix U represents uplink interference level, which is calculated by sensing result assembled by AP, u_{ij} represents the uplink interference level in channel j within the coverage of the i^{th} AP, and the unit is dBm:

$$u_{ij} = \frac{1}{L}\sum_{l=1}^{L} RSSI_{0,l} \quad (10)$$

Establish N*M AP channel allocation matrix X, data range of element x_{ip} in X is 0 and 1, where 1 represents that the i^{th} AP select the p^{th} channel, 0 represents none selection. The best channel selection problem is converted to a mathematical model in the condition of that each AP can only select one channel:

$$\sum_{p=1}^{M} x_{ip} = 1 \qquad i=1,2,\ldots\ldots,N \quad (11)$$

Up and downlink overall interference level Z of the whole network is the minimum:

$$MinZ = \alpha\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{p=1}^{M} floor[(x_{ip}+x_{jp})/2]\times u_{ij} + (1-\alpha)\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{p=1}^{M} floor[(x_{ip}+x_{jp})/2]\times d_{ij} \quad (12)$$

Floor represents round down operation, the purpose of $(x_{ip}+x_{jp})/2$ is to calculate out if there is interference among APs; same or adjacent frequency represents interference exists, and if the distance of the working frequency is far more than the width of frequency band (In 802.11n, that is 20MHz or 40MHz), it means non-interference; α represents balance of up and downlink, for example, if system is up priori, then $\alpha>0.5$ and if system is downlink priori, then $\alpha<0.5$.

After mathematic model has been set up, simulated annealing algorithm can be adopted to calculate optimal solution or second-optimal solution. The method of annealing algorithm is to exchange two rows in N*M matrix randomly. The more times they exchanged, the bigger the deviancy is, and the bigger probability of getting an optimal solution is.

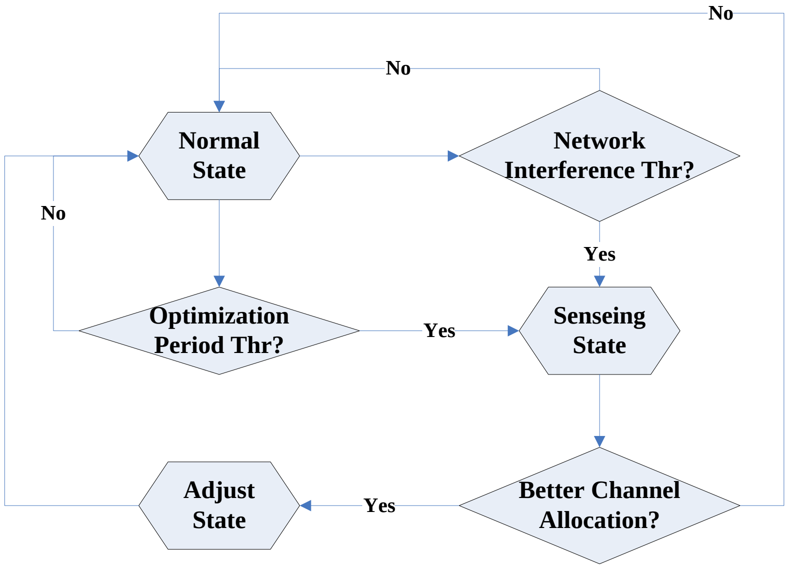

Figure 6. Procedure of Network Optimization

② Network Optimization strategy

After acquiring optimal solution, optimization strategy needs to be implemented, to ensure the channel updating disturb the normal data service in the minimum and to avoid network repeatedly optimization leading to Ping-Pang influence.

Optimization strategy includes periodical trigger and event trigger. Periodical trigger means periodically start network interference level sensing according to presupposed optimization period; while event trigger means trigger network interference level sensing to start optimization after some network KPI has been worsen to some extent due to interference. Generally we regard whole network throughput degradation or network radio PER(packet error ratio) as trigger threshold, and the later one is more popular [16]. The detailed procedure is showed in Figure 6.

Section III mainly describes on several key technologies of WLAN system based on WSN, and among them, cooperative spectrum sensing is the theoretical basis; and nodes communication procedure mainly describes on how the specified WSN works; at last, the algorithm and procedure of network optimization based on cooperative sensing result is proposed. The next section would analyze on system's gaining based on experimental scenarios.

4. Experiment Analysis

The direct improvement that we adopt WSN into WLAN system is to enhance the ability of spectrum sensing with more accurate and sensitive on wireless environment. So we design experiment I to compare single AP's sensing ability to cooperative spectrum sensing ability based on WSN.

The improvement of spectrum sensing ability cannot directly improve network performance, but accurate spectrum sensing ability can help system select better channel combination to avoid mutual interference, thus bring better network experience. So in experiment II, an indoor high-density cover scenario is chosen to compare WLAN based on WSN, WLAN without sensing ability and WLAN based on AP sensing. Network real-time and average throughput can be considered as measure index for whole network performance; higher throughput means better performance. Besides, channel SNR measure result acquired from sensor node by AP can be considered as qualitative analysis index for reflecting network interference level.

4.1. Deployment Scenario

We select an employees' dining room of 40 meters in length, 30 meters in width and 3 meters in height. The dining room can support nearly 500 persons to have dinner together, which can be regarded as a typical high density WLAN deployment scenario. There are 7 APs distributed evenly, and installed behind the 7 pillars of the dining room, as Figure 7 shows. AP1~AP6 are the working thin AP, which provided WLAN coverage and data service to the diners. On the contrary, AP7 and Microwave Zone work as internal and external interference source. As we have mentioned in Section 2, 6 working APs are also playing a role of Sink Node (AP) and 6 sets of customized UE is deployed under each AP as Sink Node (UE), which can communicate with Sink Node (AP) and sensor node according to the procedure described in section 3.2. Finally, 100 sensors is distributed randomly in the scenario. Each sensor node can do spectrum sensing for 13 channels of 2.4GHz WLAN system, and send the result to sink node on 5GHz frequency band. The parameters of the WLAN system based on WSN are described in Table 1.

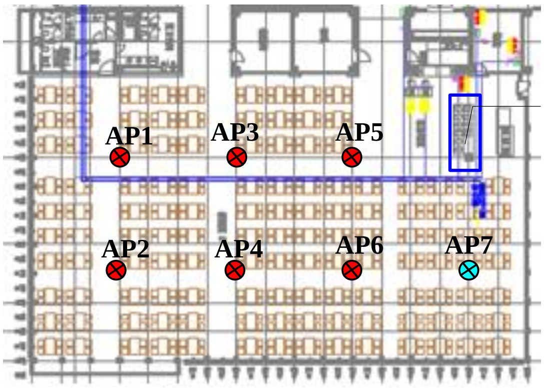

Figure 7. AP Locations in the Employees' Dining Room

Table 1. Parameters of WLAN based on WSN

Common Parameters	Description
AP type	WA201-DK-NE
Antenna type	Internal antenna
Antenna gain	2dBi
Working channel	2.4G, 13 channels 2412MHz~2484MHz
Working bandwidth	20MHz
Transmit power	100mw(20dBm)
MAC layer	DCF(Distribution)
Initial channel distribution	Channel 1, 6 and 11
Up and downlink balance α	α=0.5, there is no priority for up and downlink
Network optimiza -tion period	30min
Event optimization threshold	Whole network radio PER(packet error ratio) > 40%

4.2. Experiment I

Test purpose: to compare the sensing ability of cooperative spectrum sensing with single AP sensing.

Test scheme: AP7 works in channel 6, and one set of STA is doing FTP download service under AP7; the sending power of AP7 respectively chooses 7 gears: 20dBm, 17dBm, 14dBm, 11dBm, 8dBm, 5dBm, 2dBm; AP sensing refers to making AP1~AP6 enter measure model, and channel is considered to be occupied when spectrum scan RSSI>=-80dBm; cooperative spectrum sensing means AP1~AP6 depend on spectrum sensing result of sensor node, and channel is considered to be occupied when spectrum measure result of more than 2 sensor nodes is RSSI>-80dBm within AP coverage.

Test result is showed in Figure 8. Test result shows that when AP distance is relatively far (AP1/2 to AP7) as the scenarios a) described in Figure 2, or there is obstruction among APs (AP3/4/5 to AP7) as the scenarios b) described in Figure 2, cooperative spectrum sensing can effectively promote spectrum sensing ability for more accurate reflection on wireless environment.

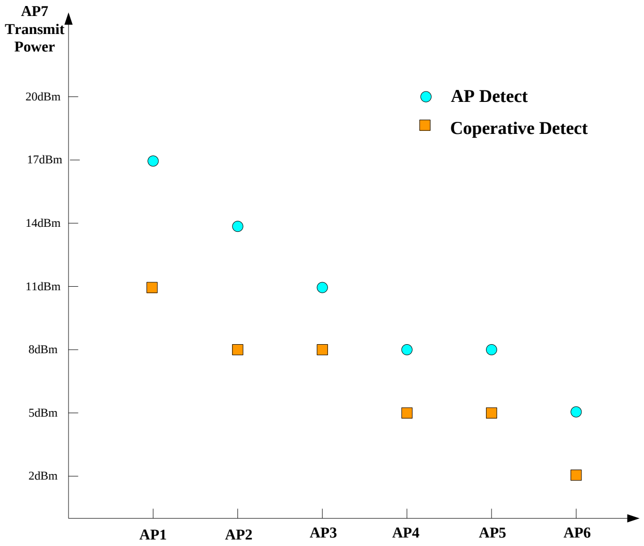

Figure 8. Comparison on Test Result between Cooperative Spectrum Sensing and AP Independent Sensing

4.3. Experiment II

Test purpose: to compare network throughput and average interference level between WLAN based on WSN and WLAN based on AP sensing ability, and non-sense ability WLAN system.

Table 2. Description on Three Sensing Programs

Program one: non-sense ability	Randomly distribute channels, among them, AP1: channel 1; AP2: channel 6; AP3: channel 11; AP4: channel 11: AP5: channel 6; AP6: channel 1
Program two: sensing ability based on AP	Start AP network sensing every 30min, and adjust channels according to sense result.
Program three: based on WSN	Initial channel distribution is based on WSN sense result; after that threshold trigger optimization is based on network radio PER (packet error ratio) and time period.

The rush hour of employees' dining room every day is 11:00-13:00, and Wi-Fi user's number peak exceeds 120. Microwave oven using peak-hour is 11:30-12:30. Therefore, our test starts at 11:00 and lasts to 13:00, and conducts sampling on network throughput and network radio PER(packet error ratio) every 2 minutes.

August, 5^{th} 2014: complete system test in program one, and channel distribution is fixed on 1, 6 and 11.

August, 6^{th} 2014: complete system test in program two.

August, 7^{th} 2014: complete system test in program three, and the following result is acquired.

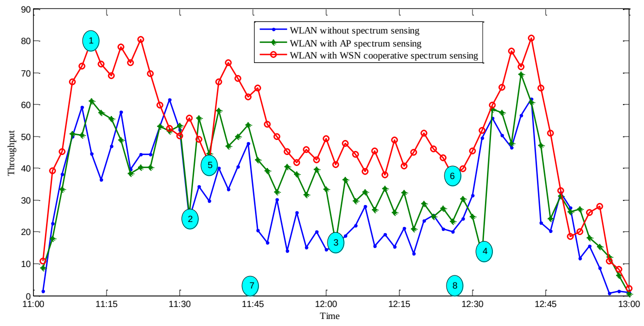

Figure 9. Comparison on Dynamic Network Throughput Capacity

Comparison on the whole network dynamic throughput is showed in Figure 9. As showed in Figure 9:

Position1: WLAN based on WSN has acquired the best channel combination by means of accurate environment measurement, so program 3 at location 1 has acquired the highest system throughput.

Position 2, 3 and 4: WLAN based on AP sensing would start once environment sensing every 30 minutes, and system throughput is reduced because sensing and operation cannot be done simultaneously.

Position 5: as a result of microwave oven interference, the packet loss rate of WLAN based on WSN exceeds 40%, which triggers the network optimization. And network throughput raise obviously after optimization.

Position 6: trigger period optimization at 12:30 and after that throughput recovers to its best level.

Position 7 to 8: as a result of broadband interference on microwave oven, network throughput in three programs has been affected. But program 3 can select channels combination of relatively less interference, so that its total throughput is relatively high.

The experiment result shows that the SNR in channel selected by WLAN based on WSN is relatively high and interference between channels is less; compared with non-sense ability WLAN system, the whole network throughput promotes by 66%; compared with WLAN based on AP sensing, the whole network throughput promotes by 38%, as shown in Figure 10 and Figure 11.

WSN's accurate measurement on spectrum enables the improvement of WLAN system sensing ability, and integrating network optimization strategy, so network can always work on channels combination with the least interference. Thus better network performance is acquired.

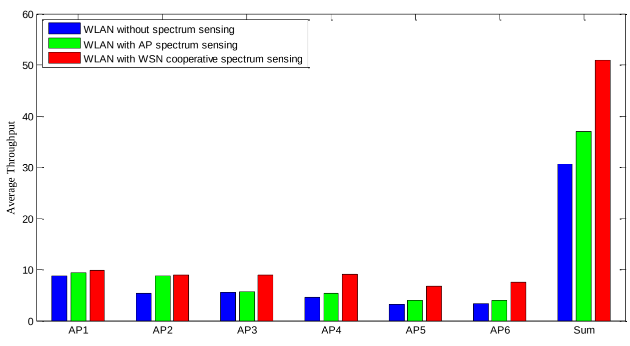

Figure 10. Comparison on the Average Throughput Capacity

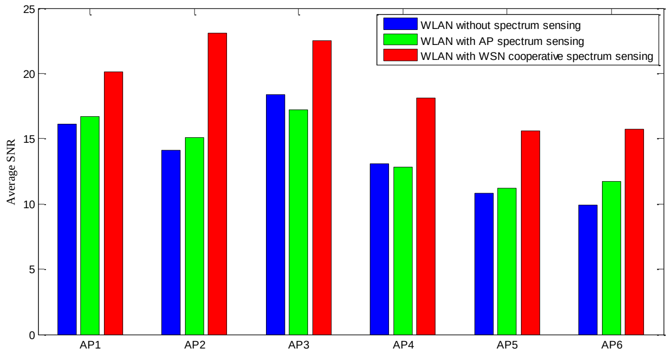

Figure 11. Comparison on AP's Average SNR

5. Conclusion

The application of WSN in WLAN system improves system's "cognition" ability fundamentally to acquire more accurate electromagnetic environment, which is helpful for network optimization and performance improvement in the end. This paper proposes theoretical foundation and detailed executable solution by study on this system's key technologies: cooperative spectrum sensing, node communication process and network optimization. The experimental result indicates that in the same test condition(distance, power and obstruction condition), cooperative spectrum sensing ability is much better, which is just in line with theoretical analysis; and compared with WLAN system based on AP sensing ability and WLAN system without sensing ability, the new WLAN system are greatly improved in its throughput and anti-interference level.

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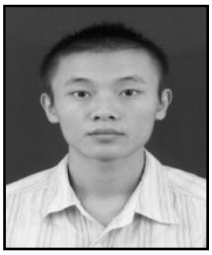

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