KAI DONG[1,*],
ZHIHONG XUE[1],
HAIXIA LIU[1]
YANWU DONG[1]
PENGJIE HE[1]

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Research on Anti-jamming Technology of Transmission Line Heterogeneous Wireless Network

Since the wireless mesh network (Mesh) equipment is installed on the high-voltage overhead transmission tower in the field, the broadband wireless mesh network (WMN) must be able to resist potential interference factors against the power communication network (such as nearby co-frequency 802.11 equipment, Microwave ovens, malicious jamming attacks against the power grid, etc.), these potential interferences cause the throughput of 802.11 devices to drop sharply or even fail to work. To this end, this article proposes an anti-jamming technology based on spectrum situational integrated perception, and conducts simulation experiments. The results confirm the feasibility of this technology and can be used to improve the anti-interference ability of 802.11 mesh equipment in the harsh magnetic environment of transmission lines. Ensure the normal operation of the power grid.

Keywords: Anti-jamming technology; transmission line; 802.11 equipment.

1. Introduction

The construction of the information infrastructure of the power system first needs to solve the problem of wireless transmission of information. The transmission of monitoring and control commands for existing power equipment is mainly based on the mobile network of the mobile operator, through SMS or General Radio Packet Service (GPRS) data channel. Realize the wireless transmission of information, but SMS or GPRS uses a shared channel and no service quality control mechanism. The transmission rate and delay cannot be effectively guaranteed, and the real-time, reliability and data security cannot be guaranteed. And it is basically impossible to transmit information such as large amounts of video images [1-4]. The long-term evolution (LTE) and wireless local area network (WLAN) of commercial centralized management rely on infrastructure such as optical fiber in remote areas, which greatly increases the difficulty of implementation and maintenance costs [5-8]. So far, although broadband WMN networks have been promoted in China, they are still immature, which restricts the overall construction and development of smart grids [9, 10]. Therefore, this article will study the anti-interference technology of the heterogeneous wireless network of the transmission line to improve the anti-interference ability of the transmission line and promote the development of the power industry.

2. Notation

The notation used throughout the paper is stated below.

$b \in M \cup P$ the base station set

[*] Corresponding author: K. Dong, North building, No. 12, Nanxiaoqiang, Taiyuan, Shanxi 030001, China, China, E-mail: d408v3@126.com

[1]State Grid Shanxi Electric Power Company Transmission Maintenance Branch, Taiyuan, Shanxi 030001, China

P_{br}	the transmission power of the base station on the resource block
G_{ubr}	the channel gain between b and u on r
R_{ubr}^{nABS}	the achievable transmission rates of resource block r in base station b on non-ABS subframes
R_{ubr}^{ABS}	the achievable transmission rates of resource block r in base station b on ABS subframes
S_{ub}	user access indication
x_{ubr}	the ratio of the resource block r allocated by the base station b on the non-ABS to the user u
y_{ubr}	the ratio of the resource block r allocated by the base station b on the ABS to the user u
$\{\omega_u\}$	the weight
$\{\rho_b\}$	the received power of the reference number measured by the user
Ω_b^{CRE*}	the weight of the optimal access user service calculated based on the criterion
T_u	the user throughput

3. Broadband wireless mesh network based on comprehensive perception analysis of spectrum situation

3.1.Spectrum sensing based on power spectrum

In order to solve the problem of poor anti-jamming ability of 802.11 devices in the field, this article provides a targeted anti-jamming solution based on the comprehensive perception of the spectrum situation, and carries out simulation experiments to verify it. To put it simply, the OFDM technology in the 802.11n standard is used to detect and analyze its signal and power frequency. The principle of OFDM signal generation is shown in Figure 1.

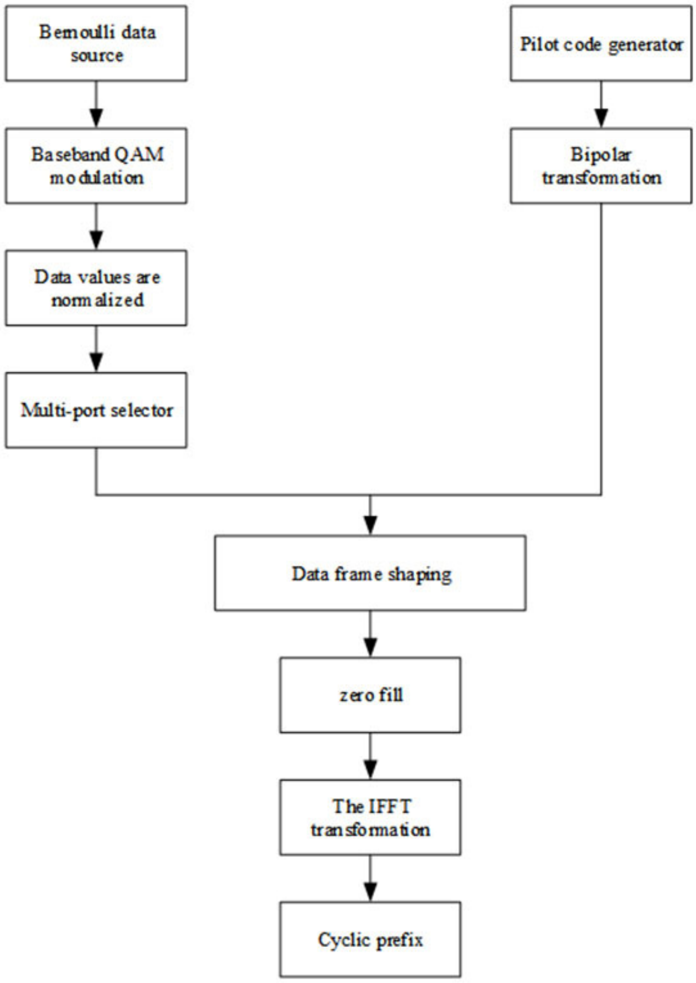

Figure 1: Principle of OFDM signal generation

Considering the complexity of system implementation, using the FFT technology in the OFDM specification to measure the existing 802.11 spectrum, the spectrum information of the channel can be obtained, and dynamic channel allocation can be performed on this basis. According to the 802.11 specification, the WLAN spectrum is divided into multiple smaller bandwidth channel units. By measuring and analyzing the power of these unit channels used to carry OFDM signals, the usage of the unit channels can be obtained. In order to simplify the calculation of channel spectrum detection, the average power of the received OFDM signal and the pre-stored power of the corresponding unit channel can be cross-correlated. Through this channel detection method, the occupancy of a certain unit channel can be estimated, and then obtained The current state of the 802.11 spectrum, the specific process is shown in Figure 2.

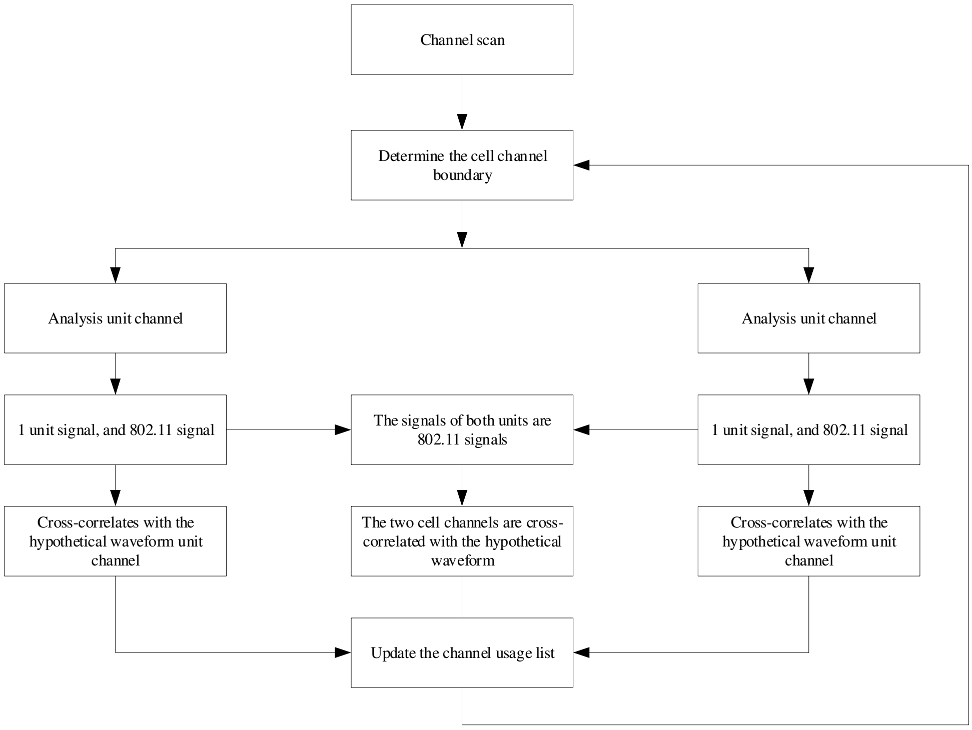

Figure 2: Frequency-frequency detection algorithm flow

The advantage of this matching algorithm is that it can analyze the usage of all 802.11 channels, and the detection method accurately detects from the physical layer through a spectrum analysis algorithm, and has good robustness. However, this algorithm needs to actively initiate channel scanning. During the scanning process, the service will have a service recovery delay of about 5 s, and it can only detect 802.11 signal interference, and cannot detect non-802.11 interference signals, which is its shortcoming.

3.2. Indirect interference source sensing based on MAC layer parameters

Because the 802.11Mesh device studied in this article uses the mainstream Atheros chip, which supports Fusion drivers, the Atheros chip encapsulates most of the PHY layer functions. Where the HAL layer is Atheros the chip hardware layer and the middle layer of the Fusion driver. The PHY layer of the Atheros chip uses energy detection methods to sense the interference of the surrounding environment. However, the energy detection mechanism is encapsulated in the chip hardware. Therefore, the channel scanning method based on power spectrum detection in the previous section is only used for spectrum analysis. The ability to rely on the tools provided by the chip to initiate channel scan requests does not meet the real-time requirements and will cause business interruption. In this regard, we first performed a signal source scrambling test and found that when the interference source sends an interference signal to the WIFI link, the single-hop throughput decreases sharply with the increase of the interference power, and the interference reaches a certain threshold (about -30d Bm). Cause the radio frequency channel to be blocked. Analysis of the Atheros chip driver found that the two register parameters of the MAC layer PHY Error (PHYERR) and Cyclic Redundancy Check Error (CRCERR) will have certain changes. Further analysis found that when the PHY layer detects that there is no 802.11 Preamble in the data, the Atheros chip reports a PHYERR to the driver, the number of which can indirectly determine whether an external interference source is generated and the severity of the interference source. CRCERR is the number of failed 802.11 frame integrity checks. When the system successfully demodulates the 802.11 frame but the CRC check fails, the Atheros chip reports a CRCERR to the driver. Secondly, I tried different debugging methods under different center frequencies, and found that PHYERR and CRCERR have no correlation. Even if a large number of PHYERRs are generated, the number of CRCERRs is basically 0, so the test parameters only consider PHYERR. Finally, the number of PHYERRs reported by the physical layer per second under different transmit power conditions is measured, and it is known that when the power value is greater than -30d Bm, the number of PHYERRs changes less and tends to stabilize; the number of PHYERRs is at the transmit power of -10d Bm. It reaches its maximum value and then gradually decreases. Therefore, the transmit power of the simulated interference user signal source used in the experiment should be greater than -35 dbm (without considering the path loss of wireless transmission). Based on the above analysis, it can be seen that RHYERR can provide certain support for the detection of interference sources. When the MAC layer detects that the interference level reaches the threshold, it will instruct the upper layer application to trigger the channel switching process. This method senses the presence of interference sources of non-802.11 interference signals in the current channel in real time. The indirect interference source sensing process based on MAC layer parameters is shown in Figure 3.

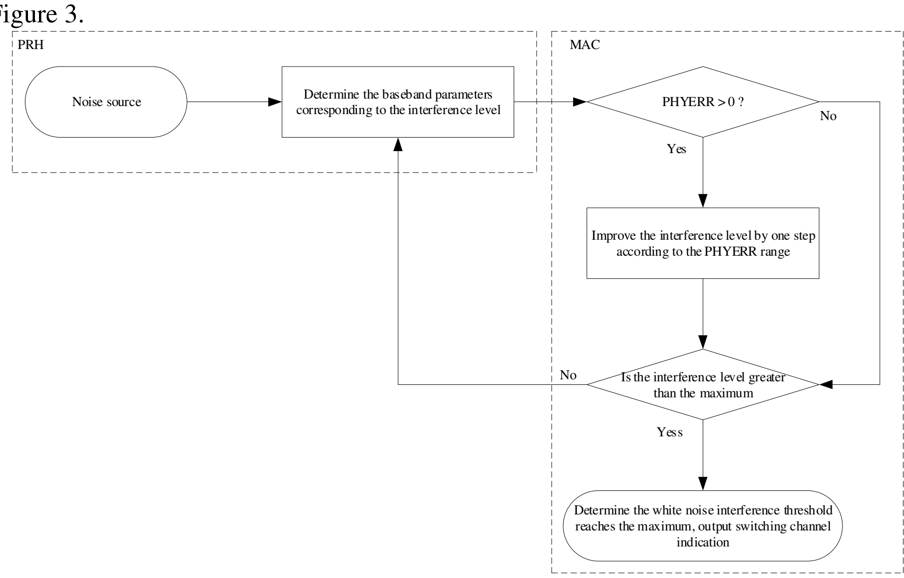

Figure 3: Indirect interference source sensing process based on MAC layer parameters

4. Anti-jamming technology based on comprehensive perception of spectrum situation

4.1. Principle and architecture analysis based on spectrum situation comprehensive sensing

Since WMN uses the same frequency network, after completing the spectrum detection work of all nodes, a centralized spectrum management strategy is adopted to uniformly transmit the node detection information to the central node, and then perform unified spectrum analysis at the central node to obtain The optimal frequency point is finally transmitted to the Mesh network node for setting. The comprehensive sensing framework based on the spectrum situation is shown in Figure 4.

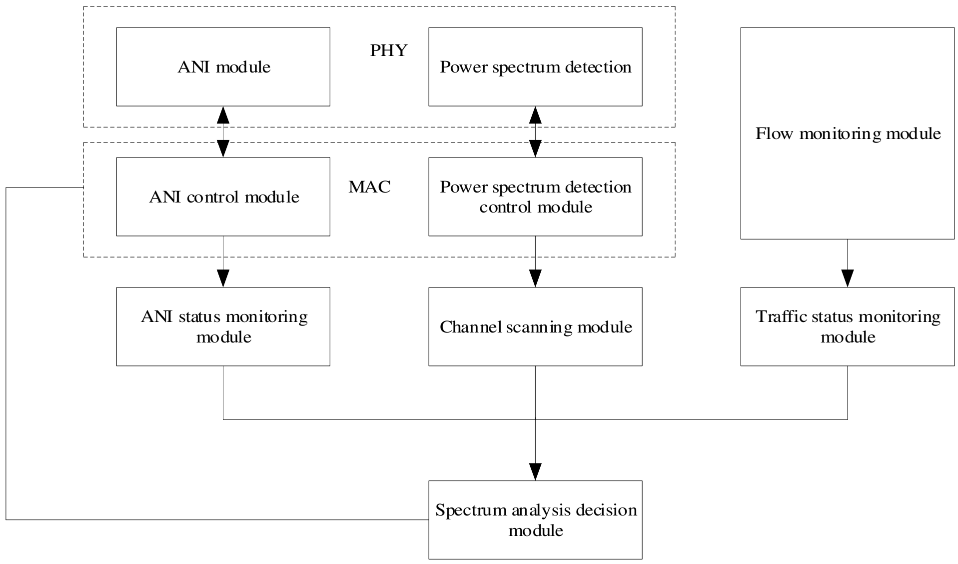

Figure 4: Comprehensive sensing framework based on spectrum situation

It can be seen from Figure 4 that it is mainly composed of nine modules including power spectrum detection module, power spectrum detection control module, channel scanning module, ANI module, ANI control module, ANI monitoring module, flow module and flow monitoring module.

4.2. Multi-point centralized anti-jamming process analysis based on comprehensive perception of spectrum situation

The multi-point centralized anti-interference process based on the comprehensive perception of the spectrum situation is as follows: First, upload the non-802.11 interference identification and the idle traffic status identification to the spectrum analysis and decision-making module. Then, each node in the Mesh network is scheduled to initiate a channel scan to obtain the scan result. Then, after finishing the node signal scanning work, start the timer to ensure that the nodes in the Mesh network return to the normal communication state. Secondly, the frequency points with the least amount of interference are screened out, and then transmitted to each Mesh node. Finally, start the timer to escort the setting of the best frequency for each node.

5. System model and problem modeling

5.1. System model construction

In order to better complete the construction of the system model, we call the access user of the small cell before adding the CRE offset as the central user (CEN), and the user after adding the offset as the extended user (CRE). In non-ABS subframes, both extended users and central users will be affected by the macro base station, but the degree of impact is different, the former is more severely affected, and the latter is less affected. Therefore, the small base station expansion user should be scheduled on ABS, and the center user should be scheduled on non-ABS. Based on the above analysis, the scheduling rules we set are as follows: First, when the macro base station user has no obvious action on the ABS, the scheduling can be done on the non-ABS. Second, the small base station extended users are scheduled on ABS, and the central user is scheduled on non-ABS. All small base stations can be regarded as a combination of central small base station (p-CEN) and extended small base station (p-CRE). At the same time, we will classify these two base stations to make them into two base station sets. Namely p_{CEN} and p_{CRE}. When the transmission power of all base stations is constant and the data is continuously transmitted to each user, the users in the ABS subframe will only be affected by the small base station, and the users in the non-ABS subframe will be affected by both the macro base station and the small base station. The SINR of the user u in the small base station b on the resource block r can be expressed by Equation 1.

$$SINR_{ubr} = \begin{cases} \frac{P_{br}G_{ubr}}{\sum_{k\in M} P_{kr}G_{ukr}+\sum_{k\in P,k\neq b} P_{kr}G_{ukr}+N_0}, & fornABS \\ \frac{P_{br}G_{ubr}}{\sum_{k\in P,k\neq b} P_{kr}G_{ukr}+N_0}, & forABS \end{cases} \quad (1)$$

Among them, the base station set is represented by b ∈ M ∪ P, the transmission power of the base station on the resource block is represented by P_{br}, and the channel gain between b and u on r is represented by G_{ubr}. At this time, let the transmission power of all base stations be $\{P_{br},\ b \in M\}$, then, in the ABS subframe, the small base station will not be affected by the macro base station, but will only be affected by other small base stations. On non-ABS subframes, users will be affected by all base stations. Therefore, the SINR of the macro base station user u can be expressed as:

$$SINR_{ubr} = \frac{P_{br}G_{ubr}}{\sum_{k\in M,k\neq b} P_{kr}G_{ukr} + \sum_{k\in P} P_{kr}G_{ukr} + N_0} \quad (2)$$

At this time, assuming that the achievable transmission rates of resource block r in base station b on non-ABS subframes and ABS subframes are R_{ubr}^{nABS} and R_{ubr}^{ABS}, then the corresponding expressions are:

$$R_{ubr}^{nABS} = \begin{cases} 1b(1 + SINR_{ubr}), if b \in M \cup P_{CEN} \\ 0, if b \in P_{CER} \end{cases} \quad (3)$$

$$R_{ubr}^{ABS} = \begin{cases} 0, \ \ if b \in M \cup P_{CEN} \\ 1b(1 + SINR_{ubr}), if d \in P_{CRE} \end{cases} \quad (4)$$

5.2. Problem modeling analysis

In order to better distinguish whether the user is accessing the base station, corresponding settings are made here, as follows: Use S_{ub} to indicate user access indication, when $S_{ub} = 1$, it means that user U accesses base station b, otherwise, it is $S_{ub} = 0$. Since the user must access a base station, its constraint conditions are shown in equation 5.

$$\sum_{b\in B} S_{ub} = 1, \forall S_{ub} \in \{0,1\}, \forall u \in U \quad (5)$$

In formula 5, $B = M \cup P_{CEN} \cup P_{CRE}$. At this time, let x_{ubr} be the ratio of the resource block r allocated by the base station b on the non-ABS to the user u, and let y_{ubr} be the ratio of the resource block r allocated by the base station b on the ABS to the user u. Since the resource funds in the base station can only be allocated to the users that it accesses, the allocation of resources needs to be restricted accordingly, as follows:

$$\sum_{u\in U} x_{ubr} = (1 - \beta), \forall b \in B, \forall r \in R \quad (6)$$

$$\sum_{u\in U} y_{ubr} = \beta, \forall b \in B, \forall r \in R \quad (7)$$

$$0 \leq x_{ubr} \leq S_u, \forall u \in U, \forall b \in B, \forall r \in R \quad (8)$$

$0 \leq y_{ubr} \leq S_u, \forall u \in U, \forall b \in B, \forall r \in R$ (9)

Considering that the logarithmic utility objective can balance the system throughput and the fairness between users, only one weighted logarithmic utility objective function is optimized here, as shown in equation 10.

$$\max_{\left\{ \substack{s_{ub}, \beta \\ x_{ubr}, y_{ubr}} \right\}} \sum_{b \in B} \sum_{u \in U} S_{ub} \omega_u lg[\sum_{r \in R}(R_{ubr}^{nABS} x_{ubr} + R_{ubr}^{ABS} y_{ubr})] \quad (10)$$

In formula 10, the service levels of different users can be determined by referring to the weight $\{\omega_u\}$. In order to reduce the amount of calculation of the optimal solution, the Gauss-Seidel method (BCD) is used to solve the problem. Specifically, it can be divided into three steps: First, given $\{S_{ub}\}$ and β, optimize $\{x_{ubr}, y_{ubr}\}$, that is, study the wireless resource allocation under the given ABS ratio and user access. Second, given $\{x_{ubr}, y_{ubr}\}$, optimize $\{S_{ub}\}$, that is, study the user's access selection situation under the given ABS ratio and wireless allocation result. Third, optimizing $\{S_{ub}, x_{ubr}, y_{ubr}\}$ for a given β, that is, studying resource allocation under a given user access situation. After sorting out, the final resource allocation results are as follows.

Optimal radio resource allocation result:

$$x_{ubr}^* = \frac{\omega_u(1-\beta)}{\sum_{k \in U_b} s_{kb}\omega_k} \quad (11)$$

$$y_{ubr}^* = \frac{\omega_u \beta}{\sum_{k \in U_b} s_{kb}\omega_k} \quad (12)$$

Standard setting, used to select the optimal access base station b for user u:

$$S_{ub} = \begin{cases} 1, if b = \operatorname{argmax}_{k \in B} \left\{ \frac{\partial f}{\partial s_{uk}} \right\} \\ 0, otherwise \end{cases} \quad (13)$$

Among them, the Heuristic Association can be used to solve the user access problem. The specific operation process is as follows: first, measure the reachable rate from each base station of all users to itself, and transmit it back to the base station; second, the user’s service weight and transmission To other base stations, and receive the achievable rate returned by the user; fourth, the access user selects the optimal access base station; and fourth, the user selects the handover user based on the optimal access base station. At this point, the user access problem is completed, and the Optimal ABS ratio is:

$$\beta^* = \frac{\sum_{b \in P_{CRE}} \sum_{u \in U_b} \omega_u}{\sum_{u \in U} \omega_u} \tag{14}$$

It can be seen from Equation 14 that the ratio of the CRE user service weight to the total user service weight is equal to the optimal ABS ratio. This is because ABS can only provide services for CRE users. However, it is worth noting that the calculation of the ABS ratio does not limit the base station, and the user service weight can be obtained from different base stations to complete the corresponding calculation.

5.3. Dynamic CRE Strategy

On the basis of a given ABS ratio and resource allocation results, this paper chooses a CRE biased user access selection strategy as the algorithm for optimizing user access, as shown in Equation 15.

$$\mathrm{b} = \mathrm{argmax}_{\mathrm{k}}\{\rho_{\mathrm{k}} + \alpha_{\mathrm{k}} | \forall \mathrm{k} \in \mathrm{M} \cup \mathrm{P}\} \tag{15}$$

In Equation 15, the received power of the reference number measured by the user is represented by $\{\rho_b\}$. In the macro base station, $\{\alpha_b\} = 0$ is biased, while in the small base station, its value is set to a negative number. However, the conversion process of this algorithm is more cumbersome and requires centralized calculation. Therefore, we choose a dynamic CRE configuration algorithm to optimize user access selection. The specific idea is as follows: CRE is adjusted on the basis of the criterion (Equation 13), that is, the service of CEN users and CER users connected in small base station b The weight sum is denoted by Ω_b^{CEN} and Ω_b^{CRE}, respectively. The weight of the optimal access user service calculated based on the criterion (Equation 11) is represented by Ω_b^{CRE*}. If $\Omega_b^{CRE*} > \Omega_b^{CRE}$, then it can be concluded that the CRE user weight sum accessed by the small base station is smaller than the optimal weight sum, and the CRE bias needs to be increased. On the contrary, it is necessary to reduce the CRE bias.

6. Simulation test

Considering that this article is studying a two-layer LTE heterogeneous network including small base stations and macro base stations. Therefore, we will use a system simulation model that includes channel quality feedback, time-frequency resource block scheduling, and link state adaptive dynamics. In this model, the transmission power of the small base station is set to 30dBm, and the transmission power of the macro base station is set to 46dBm, which is evenly distributed to each time-frequency resource block. A hotspot area with a small base station as the center and a radius of 40m is defined. The parameter setting is shown in Table 1.

Table 1: Related parameter settings

Network topology	7 cellular three-sector acer stations, base stations spacing 500m, and each sector evenly distributed 2 small base stations
Number of users and service weights	1260 users, the same service level
User's location	Each small base station has 20 users evenly distributed within a radius of 40m, and the remaining users are uniformly distributed to the macro base station
Transmission power /dBm	Small base station 30, macro base station 46
The frame length/ms	10
Carrier and bandwidth /MHz	2140; 20
Shadow fading model	TS 36.942, City model
Fast fading model	Lognormal distribution, standard deviation 10dBWINNER; B IIChannel Models
Noise power density (dBm* HZ^{-1})	-174
User movement rate (KM* h^{-1})	0 or 5
Amount of data sent	Unlimited data

6.1. System simulation in a fixed user scenario

Based on the previous foreshadowing and the setting of related parameters, a scene where the user's position is fixed is simulated here. Through the traversal experiment, it is found that when the CRE bias is 18 dB and the ABS ratio is $\beta = 0.4$, the system performance is optimal. Therefore, in subsequent experiments, we will use this parameter as a benchmark for performance comparison. Using different combination algorithms to solve the 5-10 problem, the results obtained are shown in Figure 5.

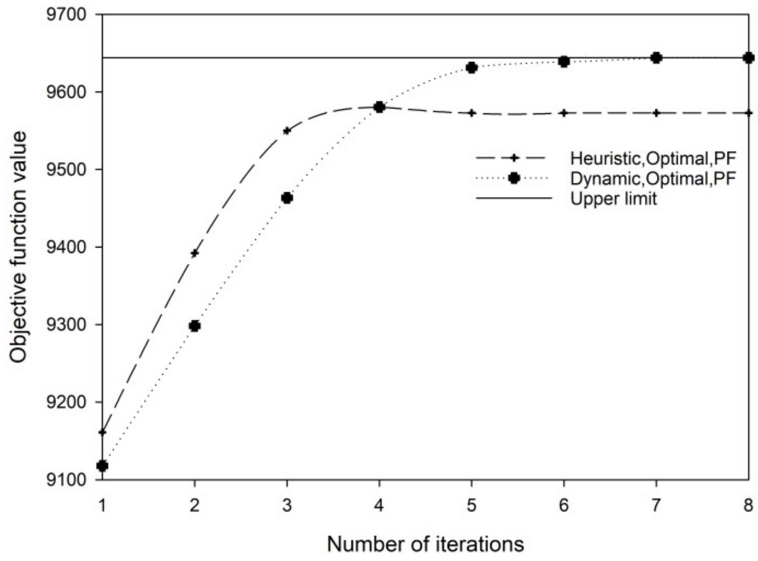

Figure 5: Solving results of different algorithm combinations

It can be seen that the heuristic user selection strategy combined with the optimal ABS ratio (PF) algorithm has convergence. Similarly, the dynamic CRE strategy combined with the optimal ABS ratio (PF) also has convergence behavior. But the former algorithm combination is closer to the upper limit of user performance. This is due to the result of the heuristic user selection strategy when solving the user access selection and the solution result of the dynamic CRE strategy. Next, we also measured the cumulative density of the user's average throughput in a fixed user scenario, and the results obtained are shown in Figure 6.

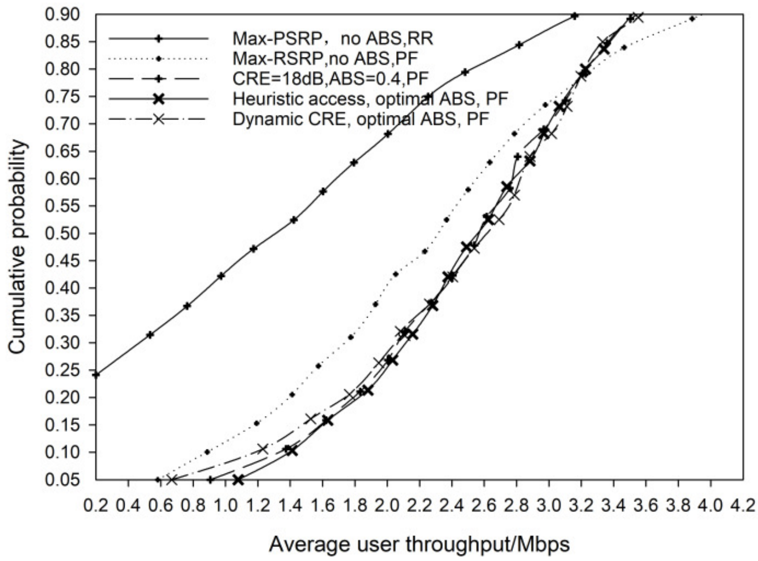

Figure 6: The measurement results of the cumulative density of the average user throughput in the user-fixed scenario

As can be seen from Figure 6, in LTE-A, round-robin scheduling (RR) is an optional scheduling strategy. Compared with the traditional RSRP access selection algorithm, this algorithm can effectively improve user performance. Compared with the heuristic user selection strategy combined with the optimal ABS algorithm combination, the user performance under the fixed CRE bias combined with the ABS ratio combination algorithm and the dynamic CRE strategy combined with the optimal ABS ratio combination algorithm is slightly insufficient. This is because of the heuristic user selection The strategy can accurately calculate the information caused by the user's access to the base station. In order to better reflect the fairness of performance between users under different algorithm combinations, we use the jain fairness index (Equation 16) to define:

$$f = \frac{\left(\sum_{u=1}^{N} T_u\right)^2}{N\sum_{u=1}^{N} T_u^2} \qquad (16)$$

In the formula, T_u is the user throughput. According to statistics, the fairness index between users under different algorithm combinations is shown in Table 2.

Table 2: Statistics of fairness index among users under different algorithms

Algorithm combination	Fairness index
Maximum RSRP access option, no ABS, RR	0.356
Maximum RSRP access option, no ABS, PF	0.452
CRE bias 18dB, ABS ratio 0.4, PF	0.657
Heuristic access selection, optimal ABS ratio, PF	0.689
Dynamic CRE strategy, optimal ABS ratio, PF	0.663

It can be seen from Table 2 that the algorithm designed in this paper can effectively improve the fairness between users. In the case of using proportional fair scheduling, the system utility situation under different algorithm combinations is shown in Figure 7.

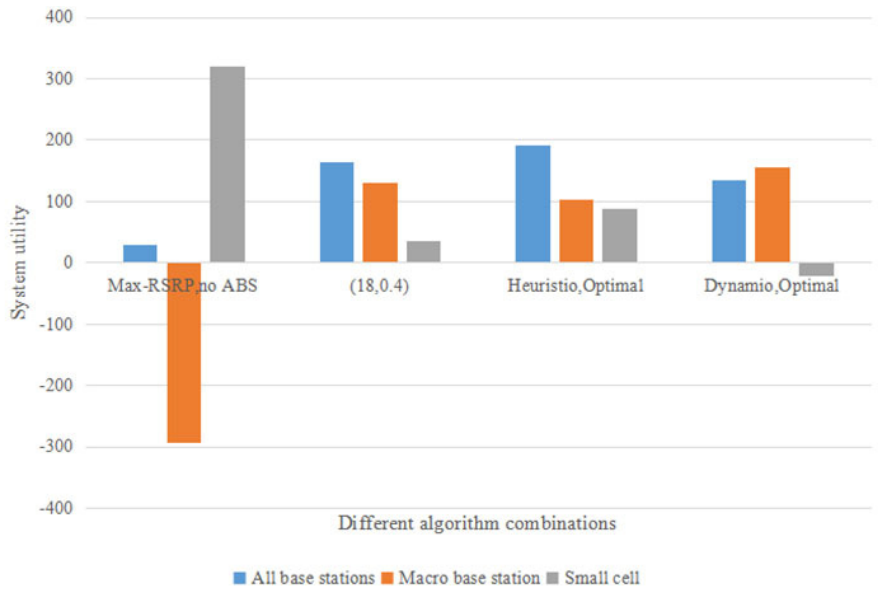

Figure 7: The system utility situation under different algorithm combinations

It can be seen that the CRE bias is 18dB, the ABS ratio is 0.4, the heuristic access selection strategy combined with the optimal ABS, and the dynamic CRE strategy combined with ABS are more effective than the traditional PSRP access system. This is the result of the first three solutions that can improve the performance of cell edge users.

6.2. System simulation in user mobile scenarios

Although the above simulation tests on the system performance of different algorithm combinations in the CPE fixed location scenario, the LTE private network needs to provide access services for mobile users in addition to the fixed CPE access services. Therefore, here is The system with different algorithm combinations in all user mobile scenarios in the network was simulated, and the mobile speed was set to 5 km/h. Finally, the average throughput of users calculated without algorithm at different time intervals (10s, 20s, 50s) was obtained, as shown in Figure 8.

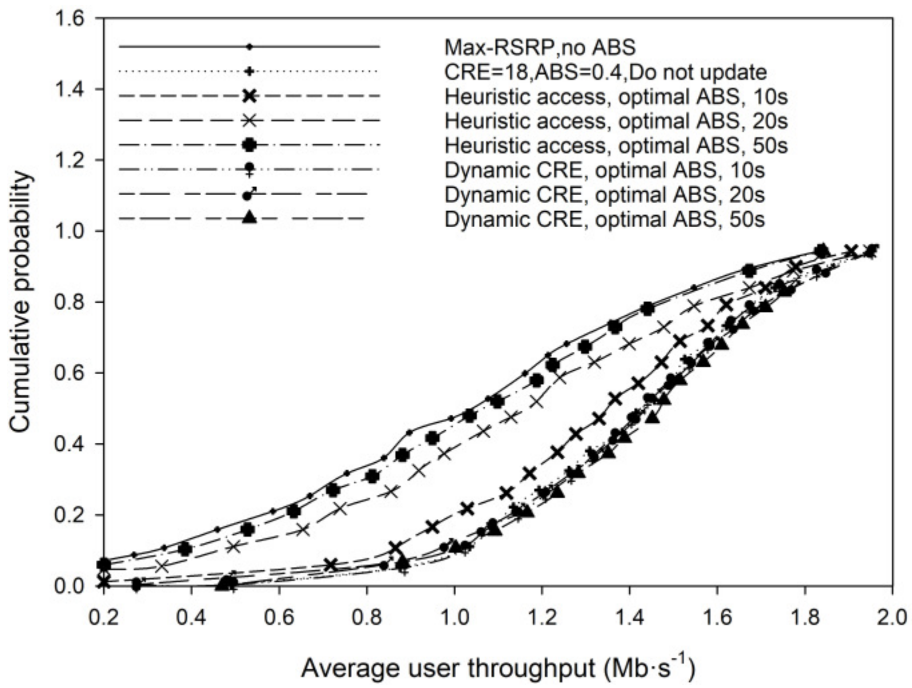

Figure 8: Display of the average throughput of different algorithm call intervals in the user mobile scenario

It can be seen from Figure 8 that the sensitivity of the algorithm combination call interval of the heuristic selection strategy is higher than that of the CRE biased algorithm combination. This is because under the CRE bias strategy, the user will perform handoff based on the bias value, while under the heuristic access selection strategy, the user will handoff when the algorithm is invoked. When the algorithm call time is too long, the heuristic access selection strategy will make the system configuration unable to match the user's actual situation. The performance of the fixed CRE configuration scheme is basically the same as that of the dynamic CRE strategy. This is because all users are in a state of random movement in this scene, and there is no obvious change in the spatial distribution. If the user's spatial distribution changes significantly, then the user system performance advantage under the dynamic CRE strategy scheme is greater.

7. Summary

In general, this article first analyzes the WMN interference problem and the current situation, and proposes an anti-interference technology based on the comprehensive perception of the spectrum situation. This method is mainly composed of the power spectrum detection method and the MAC layer indirect interference source detection method, and realizes the Mesh The equipment's true sense of spectrum situation comprehensive sensing capabilities and centralized spectrum analysis and decision-making capabilities. Secondly, the construction of the model and the analysis of the problem model have been completed, and it is found that when the small base station and the macro base station share the same frequency resources, users located in the coverage of the low-power base station will be severely interfered by the high-power macro base station. For this reason, the three correlation problems of ABS ratio setting, joint optimization allocation of wireless resources, and user access selection are analyzed to clarify and maximize the weighted logarithmic utility of the system. Among them, the BCD algorithm and the dynamic CRE configuration algorithm are selected to solve. Finally, a simulation experiment was carried out, and the results confirmed the feasibility of the algorithm proposed in this paper, which can effectively avoid the problem of co-frequency interference of edge cells and load imbalance between base stations, improve the throughput of traffic aggregation users of edge cells, and solve network interference. The problem has made its due contribution.

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