Software Defined Radio Node Topology Deployment Method Based on Multiple Attribute Decision Making

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Abstract. Node deployment is the basis for the normal operation of sensor networks. The number and location of sensor nodes deployed in the target area determines the network topology, which will further affect other performance of the sensor network, such as network coverage, connectivity, network construction cost and service life. Therefore, in order to successfully complete the monitoring task, sensor nodes must be properly deployed. This article expounds the establishment principles of the decision-making index system and the problems that should be avoided in the establishment of the decision-making index system, clarifies the nature and classification of the decision-making index, and focuses on the method of determining the decision-making index system. We explained the deterministic attribute index and the normalization method of interval numbers, and classified the normalization method of the deterministic attribute index into [0,1] interval normalization methods and non-[0,1] interval normalization methods. The advantages and disadvantages are analyzed, and the interval attribute value normalization method based on the preference of decision makers is proposed. This article discusses and analyzes the existing schemes of computer-assisted radio node topology deployment in cognitive radio networks. Aiming at the distributed cognitive radio network topology, the behavior model of authorized users is established to achieve the purpose of spectrum prediction, and it is applied to the scheme of pre-spectrum computer-assisted radio node topology deployment.

Keywords: Cognitive Radio Network; Node Topology Deployment; Multi-Attribute Decision-Making; Computer-Aided
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1 INTRODUCTION

Compared with traditional wireless transmission, the radio network has the characteristics of self-organizing network, high robustness, adaptability of nodes to harsh environments, high node distribution density, and low cost of a single node. Most radio network nodes have limited energy resources and cannot complete a large number of tasks for a long time [1]. Signal transmission technology is the top priority [2]. Usually due to energy constraints, network nodes fail, which requires radio networks to have higher transmission efficiency [3]. Because the fading phenomenon always exists in the wireless channel, it means that the wireless signal will be weakened during the transmission [4]. As the transmission distance increases, the transmission power can only be increased to meet the transmission demand, so how to increase the transmission distance without changing the transmission power is also the focus of research.

The static deployment plan of the node is often started before the network, and the performance is selected according to the characteristics of the location. The deployment plan is independent of the state of the network and runs through the entire network life cycle. In order to extend the life cycle of the network or minimize transmission delay, some deployment designs define different roles for nodes. This kind of network containing different roles or nodes with different functions is called a heterogeneous network, and a heterogeneous network usually includes ordinary nodes, relay nodes, cluster head nodes, and base stations. Deckmyn et al. [5] pointed out that when cognitive radio users have obtained prior knowledge of authorized user signals, in the case of additive white Gaussian noise channels, the best detection device is a matched filter. The disadvantage of the matched filter method is that it must have prior knowledge of the authorized user's signal. Therefore, if the prior knowledge is inaccurate, the performance of the matched filter will be greatly reduced. Therefore, for a general cognitive radio system, the matched filter method is not desirable. Based on the existing research results, Neophytou et al. [6] put forward the general structure of energy detection used in cognitive radio environment and analyzed the general relationship between its detection performance and the number of sampling points required for energy detection. The energy detection spectrum sensing method is simple to implement, but the energy detection threshold is difficult to determine due to the variability of the spectrum environment, resulting in poor energy detection performance. Deckmyn et al. [7] propose to modify the square operation of the energy amplitude in the classic detector structure to a variable value, and determine this value according to the required detection parameters, thereby improving the detection performance of the energy detector. Based on random matrix theory and statistical theory, Sharma et al. [8] have proposed a new method for accurately determining the detection threshold of spectrum sensing. The theoretical analysis results show that this method can obtain better detection performance. Yuan et al. [9] have proposed a weighted random node configuration algorithm to solve the problem of different energy consumption rates of nodes in different areas, that is, increase the density of relay nodes, so that more relay nodes can share the load, which can extend the average life cycle. Although this algorithm has a positive impact on the network lifetime, because a large number of relay nodes are deployed far away from the base station, it will cause them to leave the communication range of the base station. Varvara et al. [10] believe that the deployed relay nodes can directly communicate with the base station. Its research problem is to find the minimum number of relay nodes so that these relay nodes can be reasonably deployed to meet the constraints of network life and connectivity. The life of the network is set as the time when the first node dies. The definition of connectivity is the ability of each sensor node to communicate with the base station. Each sensor node must have its own relay node. The problem is equivalent to finding the relay node.

Since each indicator represents the attributes of the decision-making object, when establishing the decision-making indicator system, the requirements that must be met when selecting decision-making indicators are put forward. Based on the classification and analysis of the indicators, the production of decision-making indicators and the system elements of the decision-making object are summarized. We give directional guidance on the generation of decision-making indicators from the theoretical level. The reasons for the occurrence of interval numbers in attribute index

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values are analyzed. On the basis of defining the basic concepts of interval numbers, some related concepts of interval numbers are defined, and the basic operations of interval numbers are clarified. A relatively complete theoretical system is initially formed theoretically, so that when making decisions based on interval numbers, people's decisions on objective things are more scientific, rational, and standardized. The decision-making results are not only more in line with reality, but also can better integrate the information of decision-makers. We simulate the method proposed in this paper. Firstly, it proves the accuracy of the maximum likelihood estimation method used in this paper, and the effective data source guarantees the follow-up research, and then draws a schematic diagram of the application of pre-spectrum computer-assisted radio node topology deployment plan in the cognitive user communication process. It can be seen that the overall performance of the pre-spectrum computer-assisted radio node topology deployment scheme is at a relatively high level.

2 STANDARDIZATION METHOD OF MULTI-ATTRIBUTE INTERVAL NUMBER DECISION-MAKING INDICATORS

2.1 Interval Number Attribute Index Value

Decision-makers always perceive, predict, and judge things in a complex and dynamic decision-making space, which is full of uncertainty. The development of objective events is generally not transferred by human will, but is an objective existence, regardless of people. The results are neither controllable nor accurate predictions. Just as there are only two results of a coin toss, but each result cannot fully control the direction of landing. Even the deterministic decision-making information inevitably contains certain characteristics of uncertainty. Decision-makers' understanding of decision-making schemes follows the law from shallow to deep, so the process of understanding is constantly evolving, and the characteristics of each stage of the decision-making scheme are different. It is necessary to adopt a comprehensive, connected, and dynamic perspective to deal with these uncertain factors in the decision-making process.

Due to the uncertainty and complexity of objective things, the ambiguity of people's cognitive ability and the limitations of knowledge, people's understanding of things is often uncertain, especially for developing things. This phenomenon is called the uncertainty problem. This problem needs to be studied by a new method called uncertainty mathematics by scholars, and cannot be solved with classical mathematical knowledge. It is not easy to determine when describing uncertainty. Especially in engineering systems, objectively speaking, the original data representing characteristic behaviors due to data errors caused by calculations and measurements and lack of data caused by incomplete information often show some interval numbers rather than a certain number. From a subjective point of view, because humans' understanding of things and fuzzy things does not just stop at one point, people use interval numbers to quantify things. Therefore, based on the needs of analyzing and solving problems, the interval number theory should be studied in depth. The operation relationship between interval numbers a and b is as follows:

$$a-b=\left\{\left[a^{L}-b^{L}\right],\left[a^{U}-b^{U}\right]\right\} \tag{1}$$

$$a+b=\left\{\left[a^{L}+b^{L}\right],\left[a^{U}+b^{U}\right]\right\} \tag{2}$$

$$a*b=\left\{\left[a^{L},a^{U}\right],\left[b^{U},b^{L}\right]\right\} \tag{3}$$

2.2 Determination Method of Decision Index System

The factors involved in all aspects constitute a set of factors that produce decision-making indicators. The decision index is obtained by decomposing each element of the decision element

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set. Because there is no strict boundary limitation, the decision element set can produce multiple different decision index systems. Therefore, the establishment of a reasonable decision index system is a process of finding the best among multiple different decision index systems.

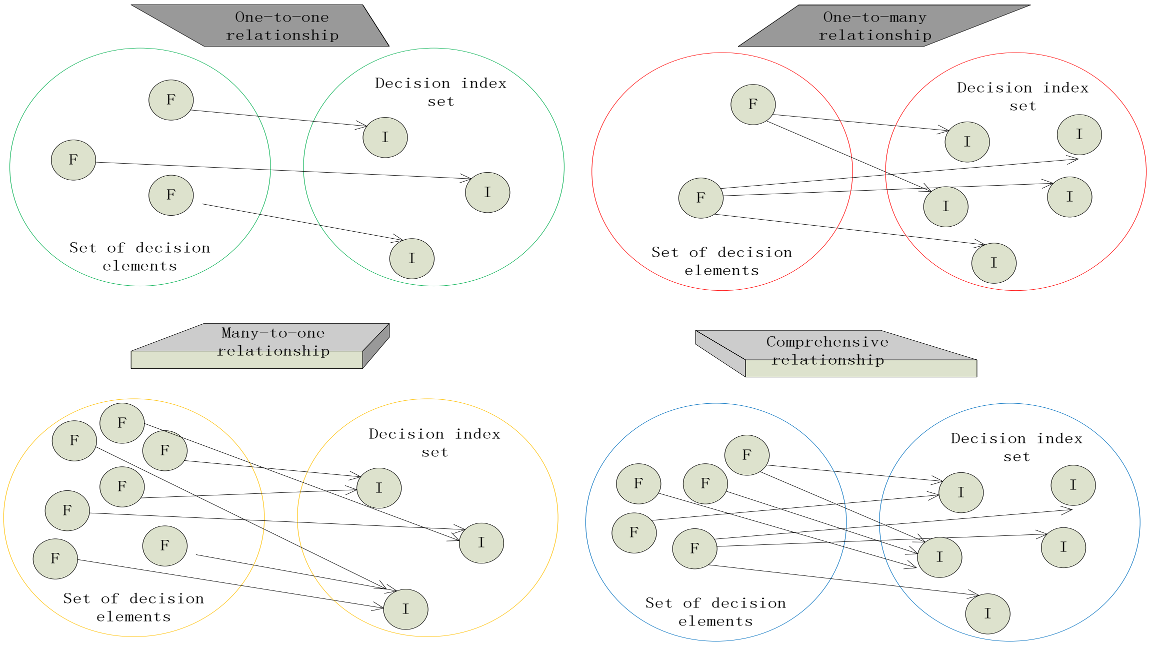

Figure 1: The mapping relationship between the evaluation element set and the indicator set.

Figure 1 shows the mapping relationship between the decision index set and the decision element set. In the final comprehensive relationship, the overlap of this connotation is more prominent.

2.3 The Standardized Method to Determine the Number Attribute Index

There is incommensurability between general attributes, which means that different attributes have different metrics. The magnitude of each attribute is different, the dimension is different, and the unit of measurement is different. Therefore, the index values of the initial attributes cannot be directly integrated. Second, the decision-making index needs to be further standardized. The standardization process here is to eliminate the type difference and dimension difference of the attribute through appropriate mathematical transformation, so that the decision-making attribute can be converted into a uniform "dimensionless" index that can be compared and processed.

For the attribute indicators before dimensionless, the above analysis will eventually fall into the two most common types: benefit-based and cost-based, so this paper focuses on the standardization methods of these two types of indicators. The benefit index is the bigger the better, also known as the positive index; the cost index is the smaller the better, also known as the negative index. The basic behavior of the benefit attribute index is strictly increasing, so it can be divided into linear, convex, convex and S, as shown in Figure 2.

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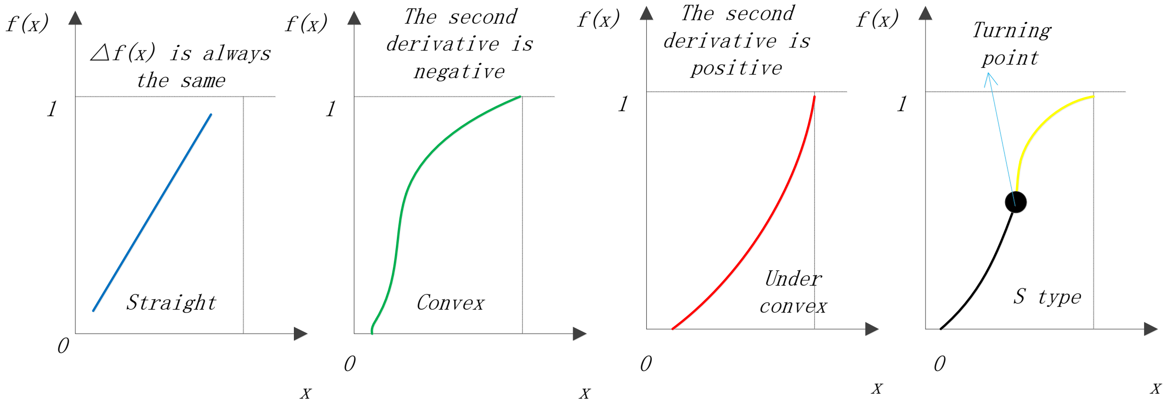

Figure 2: Performance form of benefit-type attribute indicators.

After the data of the decision plan is processed with different attribute index standardization methods, the results will be different, and the final decision results obtained based on this calculation will also be different. If an inappropriate attribute index standardization method is used to process the data, the wrong decision result will be obtained. At present, experts have not paid enough attention to the standardization methods of attribute indicators. Most of them directly use some ready-made attribute indicator standardization methods when dealing with index values. Through the analysis and comparison of several commonly used attribute index standardization methods, we seek a more reasonable attribute index standardization method for interval numbers that can reflect the preferences of decision makers, so as to solve the problem of the index standardization method.

2.4 The Interval Attribute Value Normalization Method Based on the Preference of Decision Makers

The subjective ideal point of the decision maker is used to replace the maximum and minimum values in the range transformation method. The subjective ideal point is determined by the decision maker. Benefit attribute indicators are as follows:

$$y_{ij}^{L}=\frac{\inf x_j^{*}-x_{ij}^{L}}{\sup x_j^{*}-\inf x_j^{*}}\quad j\rightarrow I_1, i\rightarrow 1,2,3,\ldots,m \tag{4}$$

$$y_{ij}^{U}=\frac{\inf x_j^{*}+x_{ij}^{L}}{\sup x_j^{*}+\inf x_j^{*}}\quad j\rightarrow I_1, i\rightarrow 1,2,3,\ldots,m \tag{5}$$

The cost attribute indicators are as follows:

$$y_{ij}^{L}=\frac{\sup x_j^{*}-x_{ij}^{L}}{\sup x_j^{*}-\inf x_j^{*}}\quad j\rightarrow I_2, i\rightarrow 1,2,3,\ldots,m \tag{6}$$

$$y_{ij}^{U}=\frac{\sup x_j^{*}+x_{ij}^{U}}{\sup x_j^{*}-\inf x_j^{*}}\quad j\rightarrow I_2, i\rightarrow 1,2,3,\ldots,m \tag{7}$$

The advantages of this method are as follows:

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(1) The positive and negative indicators are averaged into positive indicators, that is, the larger the attribute value, the better the characteristic.

(2) The standardized processing results can objectively express the relationship between the original attribute indicators and retain their original differences.

(3) Regardless of whether the attribute value is positive or negative, after normalization, the value becomes positive, which is convenient for the size comparison of the following schemes and the choice of decision-making methods.

(4) A non-linear transformation is performed, which can show that the price of the indicator changes at different starting points is different.

(5) Through the determination of the subjective ideal point, the introduction of the correlation between the plans after dimension-lessness is avoided, and the independence between the plans is not destroyed.

3 SIMULATION RESULTS AND ANALYSIS

3.1 Accuracy Analysis of Maximum Likelihood Estimation

The behavior of authorized users can be modeled as an ON/OFF index alternating model. ON (state 1) represents busy, that is, authorized users are using authorized channels; OFF (state 0) represents idle, that is, authorized users do not use authorized channels. According to the relevant knowledge of queuing theory, the arrival process of business requests satisfies the discrete Poisson stochastic process, and the arrival time interval of business requests obeys the continuous negative exponential distribution. Figure 3 and Figure 4 are the simulation results of the parameter estimation of the authorized user ON/OFF duration rate respectively.

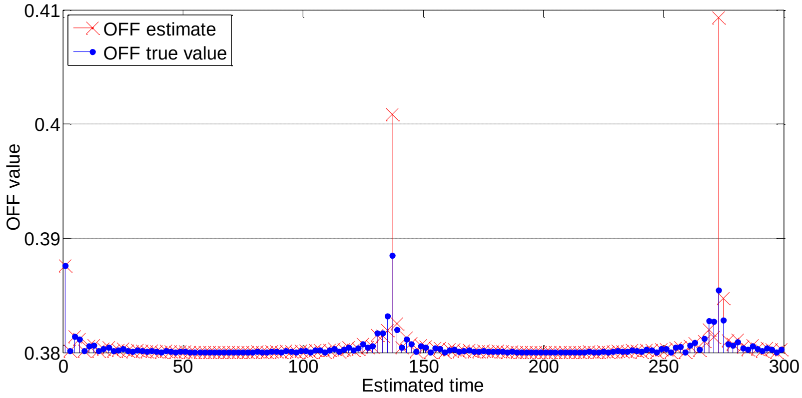

Figure 3: Cognitive users' estimation of the ON and OFF of authorized users.

At the beginning of the estimation time, due to the lack of memory of the exponential distribution, the estimated value has a large jitter. As time goes by, the estimated value gradually converges to the true value, but there is always a certain amount between the estimated value and the true value. The error is caused by the cognitive user perception-transmission cycle mode. The cognitive user observes that the authorized user ON/OFF duration is a multiple of the cognitive user perception-transmission cycle. Since the detection result will lag behind the actual activity state of the authorized user, there will be a certain offset. Errors can be appropriately reduced by shortening the perception-transmission period of the cognitive user, but a too short perception-transmission period will cause frequent conversion of the cognitive user's working mode and cause unnecessary expenses to the system. Therefore, in the parameter setting, this article selects a

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perception-transmission cycle that is within the range that authorized users can tolerate and has relatively little expense.

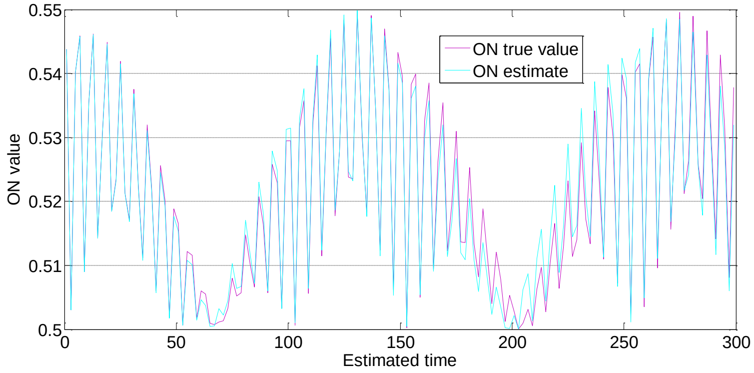

Figure 4: Cognitive users' estimation of the ON and OFF of authorized users.

Through the simulation diagram and the above analysis, it can be concluded that the estimated value of the rate parameter is still relatively close to the actual value, so it is reasonable to use the maximum likelihood estimation for the estimation of the rate parameter.

3.2 Pre-Spectrum Computer-Assisted Radio Node Topology Deployment Experiment

The authorized frequency band is fixedly allocated to authorized users, so the activities of authorized users affect the busyness of the channel in real time. We first draw the usage of 24 channels within the observation time of 300s, as shown in Figure 5. Then the pre-spectrum computer-assisted radio node topology deployment scheme proposed above is simulated. Figure 6 shows the spectrum node topology deployment state of the cognitive user using the pre-spectrum computer-assisted radio node topology deployment scheme.

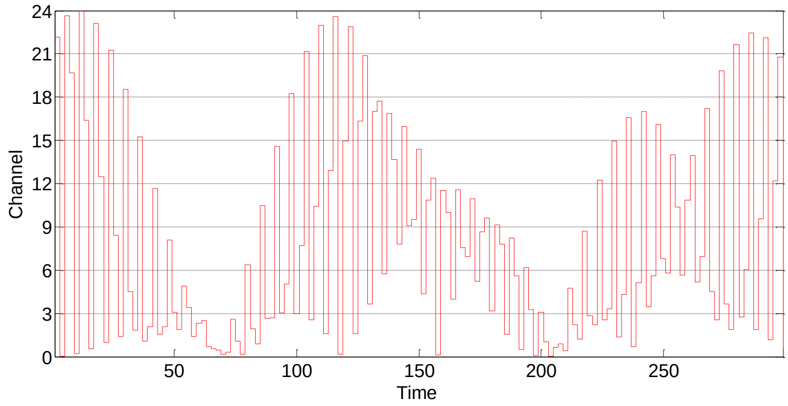

Figure 5: Channel busy/idle state simulation.

It can be seen from Figure 5 that we build authorized users into an ON/OFF model that obeys a negative exponential distribution. As time goes by, the actual busy/idle state of the channel is satisfied. The effectiveness of the model establishment ensures the subsequent analysis. As shown in Figure 6, cognitive users access the frequency bands in the distributed cognitive radio network at 70s, and use the pre-spectrum computer-assisted radio node topology deployment scheme to perform spectrum computer-assisted radio node topology deployment on different channels.

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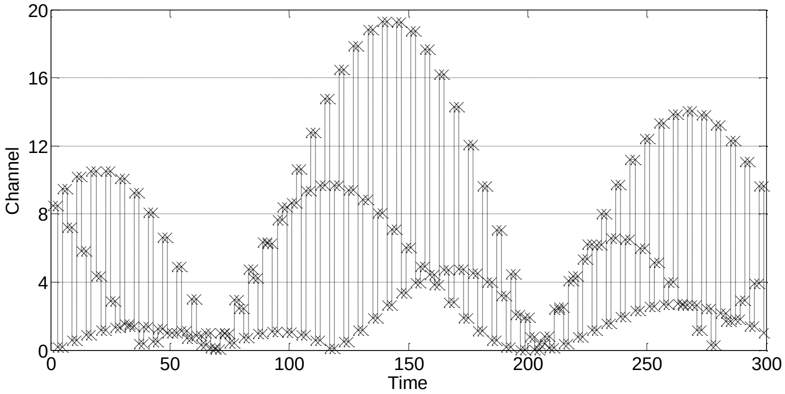

Figure 6: Pre-spectrum computer-assisted radio node topology deployment simulation.

According to the results of theoretical analysis, the computer-assisted radio node topology deployment can be performed before the authorized user comes back, that is, the computer-assisted radio node topology deployment is to a channel with a longer remaining idle time. However, when the authorized user comes back suddenly, cognitive users can only perform emergency computer-assisted radio node topology deployment, that is, they can perform computer-assisted radio node topology deployment after sensing the authorized user's signal. This is because the prediction model is based on the spectrum. The state estimation cannot fully conform to the actual activity state of the authorized user. At the same time, due to the cognitive user perception-transmission mode, it is impossible to accurately predict the activity of the authorized user, so the error within a certain range is inevitable, but the application of this method enables cognitive users to complete a good computer-assisted radio node topology deployment in the communication process, and can basically achieve intelligent computer-assisted radio node topology deployment without causing interference to authorized users.

3.3 Simulation Results and Comparative Analysis

We select the interference rate of cognitive users to authorized users as an index for evaluating the performance of the method, because this performance index is unique to cognitive radio networks and is caused by the special way that cognitive radio uses spectrum. The interference rate of cognitive users to authorized users is defined as the average number of times that cognitive users interfere with authorized users per second, that is, the probability that authorized users are interrupted by cognitive users. At the same time, the computer-assisted radio node topology deployment schematic diagram of the cognitive users adopting three schemes is simulated to verify our work.

It can be seen from Figure 7 that the pre-spectrum computer-assisted radio node topology deployment proposed in this paper and the pre-spectrum computer-assisted radio node topology deployment have relatively low interference rates for authorized users, while the traditional lagging spectrum computer-assisted radio node topology deployment has a relatively low interference rate for authorized users. The user's interference rate is much larger than the former two. However, the effect of the pre-spectrum computer-assisted radio node topology deployment scheme is not as effective as the pre-spectrum computer-assisted radio node topology deployment. The interference rate to authorized users is small. The reason is that the pre-spectrum computer-assisted radio node topology deployment finds that there is a channel in each communication time slot. When the remaining idle time is longer than the current channel, the computer-assisted radio node topology deployment will be performed.

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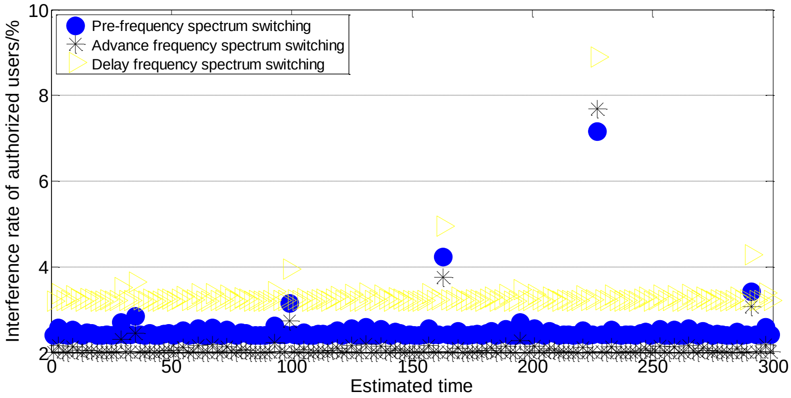

Figure 7: Interference rate of authorized users.

It is very likely that the spectrum computer-assisted radio node topology deployment will be performed in advance when the authorized user comes back for a while, which will interfere with the authorized user. The rate must be small, but this is at the cost of increasing the number of computer-assisted radio node topology deployments; and the pre-spectrum computer-assisted radio node topology deployment is arranged according to the comparison result after comparing the remaining idle time of the channel. It is possible that the demand for spectrum computer-assisted radio node topology deployment may not be obtained until the authorized user is about to arrive. Therefore, there may be cases where the computer-assisted radio node topology deployment is not timely, which will cause certain problems for authorized users. But far less than the lagging spectrum, the interference rate of computer-assisted radio node topology deployment is large, which is within the range that authorized users can tolerate.

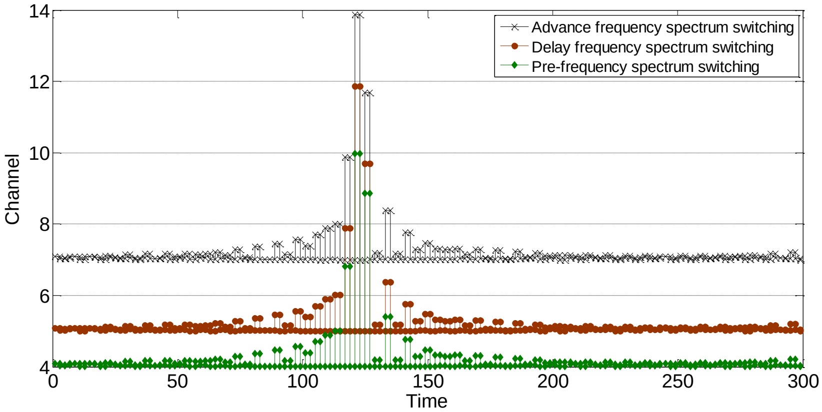

Figure 8: Comparison of different computer-assisted radio node topology deployment schemes.

As shown in Figure 8, the abscissa is our observation time, the ordinate shows different channels, and the inflection point is the deployment point of computer-aided radio node topology for cognitive users. Cognitive users access the spectrum at 70s, and perform computer-assisted radio node topology deployment on different channels to complete the traffic transmission. From the three spectrum computer-assisted radio node topology deployment schemes, it can be seen that the computer-assisted radio node topology deployment of pre-spectrum computer-assisted radio node topology deployment is the least, and the lagging spectrum computer-assisted radio node

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topology deployment has no history of authorized users, which is mainly triggered by authorized user activities to perform emergency computer-assisted radio node topology deployment, and the channel for computer-assisted radio node topology deployment is random, and the number of computer-assisted radio node topology deployments is relatively large. The deployment adopts the strategy of triggering computer-assisted radio node topology deployment by judging whether the current channel is the channel with the longest remaining idle time in each communication time slot, which leads to cognitive users who may be able to meet their own transmission needs in the current channel, and the number of computer-assisted radio node topology deployments has increased significantly; and the pre-spectrum computer-assisted radio node topology deployment scheme has corrected this defect. In general, the pre-spectrum computer-assisted radio node topology deployment has little interference to authorized users, and the number of computer-assisted radio node topology deployments is less under the same traffic volume, which basically meets our requirements.

4 CONCLUSION

The normalization methods of certain attribute indicators are classified according to the normalization methods in the [0,1] interval and the normalization methods in the non-[0,1] interval, and the normalization methods in the [0,1] interval are classified according to the linear and non-linear types. We analyze the shortcomings of the linear transformation method and the range transformation method, and analyze the application of the normalization method for determining the number attribute index in the normalization of interval numbers. A normalization method for interval numbers that conforms to the psychological characteristics of decision makers is proposed—the normalization method of interval attribute values based on the preference of decision makers. This method uses the exponential function to realize the non-linear transformation of the attribute index value through the determination of the subjective ideal point and the preference of the decision maker, which reflects the characteristic that the change cost of different starting points is different. In cognitive radio networks, due to the special working mode of cognitive radio nodes and the dynamic changes of the accessible spectrum, cognitive users need a suitable spectrum computer-assisted radio node topology deployment technology to enable it to be dynamically available. This paper studies the spectrum computer-assisted radio node topology deployment in a distributed cognitive radio network. Aiming at the problem of determining the time of computer-aided radio node topology deployment, a pre-spectrum computer-assisted radio node topology deployment scheme based on spectrum prediction is proposed. The activity model of authorized users is established with historical information, and smooth and stable spectrum computer-assisted radio node topology deployment is performed without interference to authorized users to ensure uninterrupted transmission of cognitive users.

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