Adaptive Asymmetric Frequency Hopping Communication Scheme Based on Spectrum Hole Detection

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Abstract. With the development of frequency hopping communication, the problem of anti-jamming becomes more and more prominent. According to the techniques of spectrum estimation and spectrum holes detection in cognitive radio, a adaptive asymmetric frequency hopping communication scheme is proposed. More frequency points can be found between transmitting terminal and receiving end according to the result of spectrum hole detection, the transmitting frequency tables and receiving frequency tables can be dynamically altered in real time, the anti-intercepting and anti-jamming capability of communication can be improved, and the efficiency of the spectrum usage can be promoted. This thesis is helpful to anti-jamming research, analysis and design of AFH communication systems.

Keywords: detection of spectrum hole, adaptive asymmetric frequency Hopping Communication, MTM-SVD algorithm, interference temperature, asymmetric frequency.

1. Introduction

Frequency hopping (FH) communication means that under the control of the same synchronization algorithm and pseudo-random FH pattern algorithm, the radio frequency in the predetermined frequency table (a set of N frequencies, sometimes also known as frequency set) changes pseudo randomly and synchronously in the form of discrete frequencies. The radio frequency bandwidth covered by the radio frequency in the process of hopping is far greater than the original information bandwidth, thus expanding the spectrum. Therefore, frequency hopping communication is also called frequency hopping spread spectrum communication [1,2]. Conventional frequency hopping communication has the phenomenon of "blind frequency hopping", and the other party can adopt the interference strategy of "one third frequency band / point interference" [3,4], which makes the average bit error rate increase linearly with the increase of the number of interfered frequencies, and the communication effect deteriorates or even interrupts.

In the same airspace, time domain and frequency domain, thousands of different types of frequency equipment will be concentrated, the wireless signals are highly dense and interleaved, and the spectrum resources are extremely tight. Therefore, how to overcome the "blind frequency hopping", break the interference strategy of "one third frequency band / point interference", effectively solve the
mutual interference and make full use of the spectrum resources are the urgent problems of frequency hopping communication.

This paper proposes an asymmetric frequency adaptive frequency hopping communication scheme based on spectrum hole detection. Through spectrum hole detection at both ends of the transmitter and receiver, not only more available frequencies can be found, the frequency table of frequency hopping communication can be dynamically modified in real time, and the ability of anti-interference and anti-interception can be improved, but also the problems of spectrum resource shortage and low spectrum utilization can be effectively solved.

2. Scheme design

The schematic design block diagram is shown in Figure 1

![Asymmetric frequency adaptive frequency hopping communication scheme based on spectrum hole detection](image)

**Fig. 1** Asymmetric frequency adaptive frequency hopping communication scheme based on spectrum hole detection

On the basis of symmetrical frequency table, both sides (multi-party) of communication respectively detect the local transmit and receive channels in the original frequency hopping frequency table, select the frequencies in the spectrum hole [5] to form the transmit frequency table, and select the frequency points with no interference or small interference to form the receive frequency table. Through the information exchange between the two sides (multi-party), the asymmetric frequency table is formed, that is, the two sides (multi-party) of the communication have different receiving and sending frequency tables, although the receiving and sending frequency tables at the same end are different, they are all a subset of the original frequency hopping frequency table. This result truly reflects the actual spectrum utilization, makes full use of spectrum resources, increases the number of available frequencies, and the frequency tables in two (or more) directions are not identical, which can also significantly improve the frequency hopping processing gain and competitiveness.

3. Communication process

Step 1: generate symmetrical frequency table to realize synchronous frequency hopping communication;

Step 2: detect spectrum hole and generate asymmetric frequency table;

Step 3: notification and response, confirm the intersection of judgment.
In the first step of the process, both sides (multi-party) scan the channel before frequency hopping communication, and select the intersection of available frequency sets in the original frequency hopping table to realize synchronous frequency hopping communication. Because the frequency table must be composed of both sides (multi-party) without interference or with little interference, even if the two sides (multi-party) are interfered with different frequencies and their best receiving frequencies are different, they must use the same frequency table. This makes some frequencies that can be used in one direction in the original FH frequency table excluded from the FH frequency table, and the number of available frequencies is greatly reduced, which limits the increase of FH processing gain to a great extent, resulting in the waste of frequency resources.

In the second step of the process, the sender and receiver (multi-party) respectively detect the spectrum hole in the frequency point set of the original frequency hopping frequency table, find the available frequency points, update and modify the symmetric frequency table, and generate the asymmetric frequency table: select the available frequency in the spectrum hole to form the transmitting frequency table, and select the frequency points with no interference or small interference to form the receiving frequency table.

In the third step of the process, both parties (multi-party) exchange information, and repeat the notification and response process on the passable frequency, confirm the intersection of the judgment, and finally form their own Frequency Hopping Transceiver frequency table to realize synchronous frequency hopping communication.

4. Spectrum hole detection and judgment
The detection and determination of spectrum hole is the key of asymmetric frequency adaptive frequency hopping communication. Spectrum hole is the spectrum that is not used in a certain space or time domain, or the primary user is using it, but the cognitive user can still use it by changing the transmission power or modulation mode, and the cumulative interference caused to the primary user does not exceed a certain limit (interference temperature limit). Based on the interference temperature mechanism, this paper uses multi window spectrum estimation combined with singular value decomposition algorithm (MTM-SVD) [6-8] to realize the detection and determination of spectrum holes:

Step 1: m sensors (such as receiving antennas) distributed in the detection area are used to calculate the interference temperature of cognitive users \( T_i(f) \), so as to ensure that the interference of primary users to cognitive users is within the interference temperature limit \( T_{\text{th}}(f) \):

Suppose that the time series of the received signal is \( \{X(t)\}_{t=1}^N \), the orthogonal sequence of the k-order Slepian window is \( \{w_i^{(k)}\}_{k=1}^N \), then the corresponding characteristic spectrum of the received signal is defined as the following Fourier transform form:

\[
Y_k(f) = \sum_{i=1}^{N} w_i^{(k)} X(t)e^{-2\pi j f t}, \quad k = 0,1,\ldots,K-1
\]

The MTM spectrum estimation method is used to process the signal received by the sensor, let \( Y_k^{(i)}(f) \) denote k characteristic spectrum calculated from the signal of \( i \) sensor. A space-time matrix of order \( M \times K \) \( A(f) \) can be constructed from the characteristic spectrum \( Y_k^{(i)}(f) \) as follows:
Each element of matrix $A(f)$ is related to two factors: the internal additive noise and the input RF excitation. The useful part is mainly the RF excitation. The noise can be removed by singular value decomposition. The $A(f)$ matrix is decomposed into the following forms

\[
A(f) = \sum_{k=0}^{K-1} \sigma_k(f) U_k(f) V_k^*(f)
\]

Where $U_k(f)$ is the singular vector on the left side of matrix $A(f)$, which represents the spatial distribution of interference source, $V_k(f)$ is the singular vector on the right side of matrix $A(f)$, which represents the multi window spectral estimation coefficient for analyzing interference source waveform, * represents Hermitian transform. Furthermore, we can get the matrix $A^*(f)A(f)$. The elements on the diagonal represent the average characteristic spectra of $M$ sensors for different Slepian windows. The singular values of matrix $A(f)$ are arranged in the order of their absolute values $|\sigma_0(f)| \geq |\sigma_1(f)| \geq \cdots \geq |\sigma_{K-1}(f)|$. The maximum eigenvalue $|\sigma_0(f)|^2$ is the estimated value of the interference temperature, and the linear combination of the maximum $L$ eigenvalues can be used to estimate the interference temperature, which can improve the accuracy of the estimation. In this paper

\[
T_i(f) = \frac{1}{3} \left( |\sigma_0(f)|^2 + |\sigma_1(f)|^2 + |\sigma_3(f)|^2 \right)
\]

If $T_i(f) \leq T_{zL}(f)$, proceed to the next step; otherwise, the frequency band is black space and not available.

Step 2: evaluate the maximum transmit power $P_s$ of cognitive users and calculate the interference temperature $T_{z}(f)$ of primary users to ensure that the interference of cognitive users to primary users is within the interference temperature limit $T_{zL}(f)$;

Assuming that there are $n$ primary users in the frequency band and the working frequency band is $B$, the original interference temperature $T_{zL}(f)$ at the primary user can be obtained by the method

\[
T_{zL}(f) \leq T_{zL}(f),
\]

\[
P_s \leq \frac{mP_s}{kB} \leq T_{zL}(f),
\]

\[
P_s \leq \frac{kB[T_{zL}(f) - T_{zL}(f)]}{m_i} \quad \forall 1 \leq i \leq n
\]
K is Boltzmann constant, which is equal to $1.3804 \times 10^{-23} \text{J/K}$; B is the corresponding bandwidth, $m_i \in (0,1)$ which is used to describe the multiplicative noise caused by fading and path loss between primary user receiver and cognitive user transmitter, and its value depends on the selection of spatial propagation model and the distance between primary user receiver and cognitive user transmitter.

Step 3: judge $P_s$ whether it can meet the needs of cognitive users. According to the distance between cognitive users, spatial communication model and cognitive user needs, we can judge $P_s$ whether it can meet the minimum use needs of cognitive users. If it meets the requirement, the frequency band is available spectrum hole; otherwise, the frequency band is black space and not available.

5. Conclusion

Although the asymmetric frequency adaptive frequency hopping communication based on spectrum hole detection can obtain more available frequency points, improve the frequency hopping processing gain, and improve the ability of anti-interference and anti interception, there are still many problems to be solved in the research of this scheme. Due to the complexity of the radio environment, the performance of the primary user terminal is different, so it is difficult to determine the interference temperature limit; the spatial propagation model between the primary user and cognitive user is difficult to accurately describe; the multi-party handshake protocol is needed after spectrum hole detection, which also makes the system need a long time to be stable. The above problems are the focus of future research and need further research and analysis.

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