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Study on Dynamic Allocation technology of Electromagnetic Frequency Spectrum under Regionalized Supplying Condition

Hao Liu\textsuperscript{a*}, Lin Sun\textsuperscript{c}, Fangsheng Li\textsuperscript{d}

\textsuperscript{a}Company 21, Department 6, Communication Command Academy, No. 45 Jiefang Park Road, Wuhan, 430010, China
\textsuperscript{b}Military Branches and Services Teaching and Research Section, Nanchang Military Academy, Nanchang, 330103, China
\textsuperscript{c}Modeling and Simulation Teaching and Research Section, Department of Communication Command, Communication Command Academy, No. 45 Jiefang Park Road, Wuhan, 430010, China
\textsuperscript{d}Studying institution of Communication Development Strategy, Communication Command Academy, No. 45 Jiefang Park Road, Wuhan, 430010, China

Abstract

Dynamic management of electromagnetic frequency spectrum is important to realize military regionalized supplying. In this paper, application characteristics of OFDM is firstly introduced, then OFDM system resource allocation ways and models are illustrated, and finally, typical RA subcarrier allocation algorithms are put forward, which provide theoretical reference for choosing dynamic allocation technology of electromagnetic frequency spectrum.

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1. Introduction

Regionalized supplying is a new pattern of military communication supplying. It divides operating mission area and garrison area into several supplying parts, where relative service application platforms and communication supplying power are established and deployed to carry out unified reallocation, management and application of all resources relying on military and civilian common-used comprehensive networks. For regionalized supplying, dynamic management of electromagnetic frequency

\textsuperscript{*} Hao Liu. Tel.: 18995616039 .
E-mail address: liuhaolunwen@163.com.
spectrum is very important. And dynamic spectrum allocation is critical to optimize spectrum using and enlarge channel capacity, also the key and core of regionalized dynamic spectrum management.

Under condition of regionalized supplying, due to the strong unpredictability, working time and area of traditional authorized users is uncertain, which may result in the fact that available frequency resources of spectrum cognitive users have the obvious characteristics of being disperse in time, discontinuous in frequency domain and irregular in space. To use disperse free frequency resources effectively, dynamic subcarrier distribution based on OFDM is fitting.

2. Application Characteristics of OFDM

At present, OFDM is the easiest data transmission way to realize spectrum resources controlling and effective using. It divides the given channel into many orthogonal sub-channels, and uses a subcarrier to carry out modulation in each sub-channel with parallel transmission of each subcarrier. And it has the following characteristics.

2.1 Anti-multipath Interference and Fading Capability

OFDM transforms frequency choosing fading channels into series of paralleled flat fading channels, which may overcome multipath inter-character interference (ISI). By joint coding of each subcarrier, its anti-fading capability is strengthened.

2.2 Effective Frequency Using Capability

The subcarriers are inter-orthogonal in OFDM system, and subcarrier spectrum after spread spectrum (SPSP) modulating is inter-lapped, which reduces the mutual interference of each subcarrier and improves the effectiveness of system frequency using.

2.3 Function of Frequency Spectrum Grouping and Clipping

Frequency grouping means that when user service needs a certain amount of frequency band, and available frequency is discontinuous in frequency domain, OFDM can be used to group these separate frequencies for the users. Frequency clipping is mainly used by the users who have relative low demand of frequency band. By frequency clipping, the rest frequencies can be used by other users. Thus the effectiveness of frequency using is improved.

2.4 Function of mutual-interference suppression

OFDM uses several subcarriers at a time to carry out information transmission. After the transmitting data is homo-disperse in several subcarriers, the interference induced by the fact that transmitting power focuses on one authorized user frequency band can be avoided. Meanwhile, for spectrum cognitive users, when they want to use frequency, by controlling the transmitting power of the corresponding subcarrier (Make it be 0), they can turn off some subcarriers. And only the affected data has frequency changing, which may reduce the interference of authorized users' access to spectrum cognitive users.
3. OFDM Resource Distribution Pattern

At present, resource distribution based on OFDM includes subcarrier, bit and power distribution, which may be achieved using a common separate algorithm or using different algorithms respectively. In single-user OFDM system, there is no subcarrier distribution problem. All the subcarriers are for the user to use. And the resource distribution only involves in bit and power distribution. While for multi-user OFDM system, the spectrum resource is shared by several users. The subcarrier can't be used by several users at a time. Making the limited subcarriers meet the spectrum need of all users involves in subcarrier allocation of multi-user OFDM system. And now multi-user subcarrier allocation can be divided into static (fixed) and dynamic (self-adaption) subcarrier allocation.

3.1. Static Subcarrier Allocation

For static subcarrier allocation, no matter what the current channel condition is, the system always allocates one or a group of subcarriers for each user in a fixed way, without considering the dynamic changing of channel status and users’ requirement. It is not an optimized resource allocation plan in terms of saving resource or improving system performance. And OFDM-FDMA is a common static subcarrier allocation.

3.2. Dynamic Subcarrier Allocation

For dynamic subcarrier allocation, according to the quality of current wireless channel, it can distribute, allocate and switch the subcarriers self adaptively to ensure sound service quality at any time. In OFDM system, each sub-channel is isolated and there is no or weak relativity. Channel fading is different at a given time. The deep fading subcarrier for one user may not be bad for other users. And the best subcarrier for one user may not be the best one for other users either. Therefore, if the base station can master the channel transmission specialty of network users, it can combine OFDM and dynamic subcarrier allocation, and make use of channel diversity specialty among mobile stations at different places to realize optimized resource allocation.

4. Model of OFDM Resource Distribution

OFDM resource allocation model can be analyzed as the following.

4.1. Resource Allocation Model

At present, resource allocation based on OFDM system is usually dynamic. Figure1 represents common dynamic down link resource allocation model of multiple-user OFDM system. In the model, there are M users and N subcarriers in the base station. Suppose the bandwidth of each subcarrier is far less than the relative one of wireless channel and user channel status information is known. In transmitting end, dynamic resource allocation modules can carry out subcarrier, bit and power optimization allocation of user data according to user channel information. OFDM modulating function is realized by self-adaptive modulating, and the information is transmitted to the wireless channel. And in receiving terminal, taking user M as an example, the receiver related to M receives the information and demodulates it by fast Fourier transform (FFT) modules, and extracts relative data of user M from relative subcarriers according to the information from resource allocation modules. During the realization process,
to ensure orthogonality of each subcarrier, after OFDM modulating, cycling prefix can be added to be as guard interval.

4.2. Resource Allocation Goal

According to the constraint condition and differences of optimized goal, dynamic resource allocation of OFDM has three types of goals.

Firstly, rate and bit error rate are given to minimize total transmitting power.
Secondly, total power and the need of bit error rate are given to maximize total rate of the system.
Finally, the constraint of rate and total power is given to minimize average bit error rate of the system.
And in the above, minimizing total transmitting power is also called MA and maximizing total rate is also called RA.

4.3. RA Mathematical Allocation Model

Resource allocation based on RA goal standard means that with the restriction of total transmitting power, BER and QoS, an effective subcarrier and power allocation algorithm is adopted to allocate relative subcarrier and power for each user to realize maximizing of total system capacity(rate or throughput). RA mathematical allocation model can be expressed as the following.

\[
\max \sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{m,n} \log_2 \left(1 + \frac{p_{m,n} g_{m,n}^2}{\sigma^2 \Gamma}\right)
\]

Constraint condition is:

\[
\sum_{m=1}^{M} \sum_{n=1}^{N} \rho_{m,n} p_{m,n} \leq P_T
\]

\[
\rho_{m,n} \in \{0, 1\} \quad \forall m, n
\]

\[
\sum_{m=1}^{M} \rho_{m,n} = 1 \quad \forall n, \text{ and } \sum_{m=1}^{M} \rho_{m,n} = N
\]

\[
p_{m,n} \geq 0 \quad \forall m, n
\]
In the above, $P_T$ is total transmitting power constraint. $\Gamma = -\ln(\text{BER})/1.6$ is signal to noise ratio (SNR) balance. $\sigma^2$ is noise variance. $g_{m,n}$ is channel gain generated by user $m$ in subcarrier $n$. $\rho_{m,n}$ is subcarrier allocation identifying function. When user $m$ occupies subcarrier $n$, $\rho_{m,n} = 1$; otherwise, $\rho_{m,n} = 0$.

From Formula 1 and its constraint condition, it is known that the model is a kind of nonlinear constraint and optimization question. The solving process is complex and does not adapt to dynamic resource allocation. About the question, several suboptimal algorithms are put forward, mainly including the following two types. One is to use sub-step way to realize subcarrier and power allocation. And the other is to carry out presumption to simplify the analyzing process.

5. Typical RA Subcarrier Allocation Algorithms

There are three typical RA subcarrier allocation algorithms.

5.1. Bit Rate Maximizing Algorithm

This algorithm translates joint optimization allocation of all subcarriers into respective optimization allocation of $N$ subcarriers. In order to make each subcarrier transmit largest information amount, the algorithm allocates the subcarrier to the user who has best channel specialty in it to improve subcarrier frequency effectiveness. The complexity and calculating amount of the algorithm is relatively lower. But considering the fact that the subcarrier is allocated to the user who has the best channel status every time, for the users who have discontinuous channel status, available resource can not be allocated to them for a long time. While for the users who has sound channel specialty, they may occupy the resources for a long time, which can not guarantee user fairness and QoS.

5.2. MAX-MIN Algorithm

For MAX-MIN algorithm, user who has lowest data rate has the priority to choose subcarrier. By improving the throughput of the user who has lowest data rate, approximate fairness of user data rate is assured. Its allocation steps are as the following.

Step 1: To initialize parameters.

Step 2: To allocate the subcarrier which has the largest relative channel gain to the first user. Update user data rate and subcarriers to be allocated. And then, allocate the rest subcarrier which has the largest relative channel gain to the second user, and update relative user data rate. Repeat the process until all the users are allocated with a subcarrier which has best channel specialty to them.

Step 3: If there is rest subcarriers, go ahead with second-round allocation. The user who has current lowest data rate has the priority to choose the subcarrier having best channel gain. The rest can be done in the same manner until all the subcarriers are allocated.

Although this algorithm reflects the data rate fairness among all the users, it doesn’t consider the service need and frequency using difference among the users.

5.3. Otani Subcarrier Allocation Algorithm

Otani puts forward two subcarrier allocation algorithms, which consider user data rate fairness as well as allocation timeliness. For Otani algorithms, suppose the user number is $M$ and carrier number is $N$, and subcarrier number that each user can be allocated is $k = M / N$ (k is integer). The allocation steps of the two algorithms are as the following.
5.3.1. Allocation Steps of Algorithm 1

Step 1: For subcarrier 1, allocate it to the user who has best channel specialty to it.

Step 2: For subcarrier 2, according to allocation rule of step 1, allocate it to the relative user. Repeat the process until the allocated subcarrier number of a user reaches k, and then stop the allocation to the user.

Step 3: Allocate the rest subcarriers according to step 1 and step 2 until all the users are allocated with k subcarriers.

In the above, each subcarrier is allocated to one user during its allocating process, and it can not be used by multiple users at the same time. Although this algorithm adopts the way of occupying subcarriers averagely to ensure amount fairness of user resource, but the users having sound channel specialty has the priority to occupy the subcarriers, which can’t guarantee the user’s effectiveness fairness.

5.3.2. Allocation Steps of Algorithm 2

Step 1: For user 1, choose the subcarrier which has best channel transmitting specialty from the subcarrier set.

Step 2: For user 2, choose the subcarrier which has best channel transmitting specialty from the rest subcarriers. Repeat the process until user M has its relative subcarrier.

Step 3: If there are rest subcarriers, go ahead with second-round allocation. To ensure user effectiveness fairness, the user who has last allocation in the former round chooses its sound subcarrier firstly. Repeat the process until all the subcarriers are allocated.

For these two algorithms, both ensure subcarrier amount firstly, which means that by allocating subcarriers averagely, user resource amount fairness is assured. Meanwhile, both adopt greedy allocation mechanism, which means that by allocating subcarriers having sound channel specialty to the relative users, system capacity is enlarged.

6. Conclusion

The specialty of regional frequency environment requires that spectrum dynamic allocation should follow the principle of flexible frequency allocating, effective system performance and simple signaling overhead. When the user channel transmission specialty is given, by dynamic multi-user subcarrier allocation algorithm, system gain aroused by frequency subset and multi-user subset can be improved effectively.

References

[1] Weixian Zhou. Cognitive Radio [M]. Beijing: Press of National Defense Industry, 2008.
[2] Hongyan Li. Study on several key technologies of cognitive radio .Beijing: Beijing University of Posts and Telecommunications, 2009.
[3] Hongjie Liu. Study on Dynamic Spectrum Management Theory Based on Cognitive Radio and Relative Key Technologies. .Beijing : Beijing University of Posts and Telecommunications, 2009.
[4] Serena chan. Sharing spectrum access of DOD . China Radio, 2008.3, 3: 10-14.
[5] Peyman Setoodeh and Simon Haykin. Robust transmit power control for cognitive radio . Proceedings of the IEEE, May 2009, 97(5): 915-939.