Research on Joint Working Mode of Multiple Frequency Hopping Radios Under Interference Suppression Condition

Ding YUAN*, Hou-de QUAN, Hui-xian SUN and Jian-cheng LIU
Information Engineering Department, Ordnance Engineering College, Shijiazhuang, China
*Corresponding author

Keywords: Joint working, Frequency hopping radio, Interference Suppression, Collaborative beamforming.

Abstract. A joint working mode of multiple Frequency Hopping (FH) radios is considered in this paper, which applies the cooperative work idea in FH communication. By jointly processing the resources provided by multiple FH radios, the joint working mode can get a better interference suppression performance. Four levels of joint working mode are introduced in this paper. A joint working mode using multiple antenna technology is detailed analyzed here. The mode can be realized in three methods, which are jointly transmit, jointly receive, and jointly transmit and receive. Key problems remained to be solved are also given. Simulation results show the effectiveness of the joint working mode. The joint working mode is a complement to the existing FH communication mode, which can be used to ensure normal communication in interference suppression condition.

Introduction

HF/VHF frequency hopping (FH) radios are widely used in military communication. With rising interference means, only relying on the frequency hopping mode cannot meet the interference suppression requirements. Under the current one-to-one radio working mode, the normal communication cannot be guaranteed when radio at one communication terminal is suffering from strong intentional interference from the enemy. However, more than one radio is configured at one communication terminal in practice. It is feasible to make multiple radios work together to get better interference suppression performance. The joint working mode of multiple FH radios is researched in this paper, which is a complement to the existing radio working mode.

It should be noted that there are a lot of constraints when dealing with the practical radio, while new radio based on software defined radio (SDR) is put into use in military communication and provides a new foundation to realize the joint working mode. As a theory research, the paper is discussing in the context of new SDR radio. When it comes to joint working mode of multiple FH radios, researchers have proposed a series of solutions at different levels [1]. A joint working mode using multiple antenna technology is given and detailed discussed here. Key problems need to be solved in the realization are listed and discussed. A simulation experiment is given to illustrate the effectiveness of the mode. Conclusion is drawn at the end.

Multiple FH Radios Joint Working Mode

The joint working mode can make use of resources of multiple radios at different level. It outperforms the single radio working mode by means of different technologies. Depending on resource jointly processed, the mode can be divided into four levels as shown in Table I.

At the first level, there are multiple channels and frequency hopping sequences can be used. The existing research assumed multiple channels are in the same radio [2], which proposed a high demand for radio design.

At the second level, multiple radios provide more than one antennas which can compose antenna array. Different kinds of multi-antenna technology can be used according to the form of antenna array, such as smart antenna (SA), Multiple input Multiple out (MIMO) and cooperative...
communication (CC). In this mode, by using multiple antenna technology and array information processing technology, we can realize space domain anti-interference [3].

The third level is based on FH radio networking. Unlike the first two levels, FH radio herein is treated as a node in communication network. By adopting networking protocol design, the system can get a better performance.

At the forth level, cooperative work and spectrum perception idea are combined. All FH radios in the network forms a spectrum perception system [4]. Frequency spectrum is treated as a resource which can be assigned in the whole FH radio network.

The joint working mode draws on cooperative work idea. In view of interference suppression, the anti-dilapidated ability of whole communication system is improved. Even when one radio could not work properly, the whole joint system still can realize communication.

<table>
<thead>
<tr>
<th>Level</th>
<th>Joint Processed Resource</th>
<th>Adopted Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Communication Channel, FH sequence and pattern</td>
<td>Combined frequency hopping technology, FH sequence design, Channel coding</td>
</tr>
<tr>
<td>Level 2</td>
<td>Radio Antenna, Array beam</td>
<td>Multiple antenna technology, Array information processing technology</td>
</tr>
<tr>
<td>Level 3</td>
<td>FH network, network protocol</td>
<td>FH radio networking, Network protocol design technology</td>
</tr>
<tr>
<td>Level 4</td>
<td>Frequency spectrum</td>
<td>Cooperative work technology, Spectrum perception technology</td>
</tr>
</tbody>
</table>

**Joint Working Mode Using Multiple Antenna Technology**

As shown in Section II, in order to realize interference suppression, we can perform resource allocation at system level, and employ interference cancellation techniques at physical level. Here we focus on the use of multiple antenna technology in joint working mode. Multiple antenna technology is widely used in radar, mobile communication and satellite communication. By means of antenna array, we can make use of the spatial information of the signal. The array form determines the technology used. On different occasions, antenna arrays are used in different ways and one or more kinds of multiple antenna technologies can be employed.

Here we adopt multiple antenna technology to realize interference suppression. When receiver suffers from interference, we have to enhance or maximize the Signal to Interference and Noise Ratio (SINR) or Signal to Noise Ratio (SNR) at the receive terminal in order to maintain normal communication. There are two kinds of methods to achieve this goal. The first method deals with the numerator of SNR by enhancing and maximizing the desired signal transmitted. The second one deals with both the numerator and the denominator of SINR by trying to maximize the desired signal received and minimize the interference signal received.

In this joint working mode, multiple single antenna radios forms virtual antenna array, which provides a foundation for the use of multiple antenna technology. Here considering radio background, we design and analyze three methods according to the application location.

**Jointly Transmit**

The jointly transmit forms desired transmit beampattern with a set of single antenna radio. The core of jointly transmit is trying to enhance the receive signal strength at the receive terminal so as to get a better performance of interference suppression. This method can be used in MISO and MIMO scenarios. As mentioned before, array form determines the technology used. Two basic array forms are shown in Figure 1, which are uniform linear array (ULA) and arbitrary array [5,6]. Distributed transmit beamforming is realized in ULA by employing SA, while collaborative transmit beamforming is carried out in statistical way. Another influence factor is the prior and feedback information. The transmitter can get the channel state information (CSI), the array geometry and the array performance in a feedback or predictive manner [7]. There are different ways to achieve transmit optimization according to the information obtained. In the optimization process, a number
of factors can be considered, such as transmit wave of antenna, transmit power of antenna or the whole power of transmit arrays, and the position of transmit array.

![Figure 1. Jointly Transmit Method.](image1)

**Jointly Receive**

The jointly receive method uses spatial filtering to realize interference suppression. At the receive terminal, all arrived signals are received by virtual antenna array, including the desired signal, the interference signal and the noise signal. Then in the processing center, by means of beamforming, the interference signal is filtered to the minimum while the desired signal is maximized. As shown in Figure 2, the mainbeam points to the desired signal, while the sidelobe or nulling are aligned to the interference signal. There are two issues worth noting in FH radio background. The first issue is the limited array degree of freedom (DOF). The scale of antenna array composed by multiple radios is always limited. Sometimes the number is relatively small. In this case, the array may not have sufficient DOFs to deal with all interferences. The second issue is that different beamforming schemes are used to deal with different kinds of interference. To FH radios, the follower jamming is correlated interferences, while barrage jamming is non-correlated jamming, which need different beamforming scheme.

![Figure 2. Jointly receive method.](image2)

**Jointly Transmit and Receive**

Recent research have focused on the joint design of transmit and receive beamforming [8], which originates from the joint transmit method. The two methods difference lies in that the former method tries to improve SINR instead of SNR at the receive end. The transmitter gets feedback information from the receiver and takes account of the interference in beamforming design. This design has turned into a multi-parameter optimization problem which increases the computational cost. The feedback information contains CSI and interference information, which could affect the performance of transmitter beamforming [9]. Its process is shown in Figure 3.

![Figure 3. Jointly Transmit and Receive Method.](image3)
In summarize, the jointly transmit method realizes interference suppression in the manner of focusing, while the jointly receive employs filtering manner. The jointly transmit and receive can realize focus and filter at the same time. But its computation burden is also increased. Their performance will be verified in the following sections with a Simulink experiment.

**Key Problem Remained to be Solved**

There are some key problems remained to be solved in the implementation of joint working mode using multiple antenna technology. The problems are related with algorithm design and hardware implementation as listed.

**Distributed Processing**

Whether a set of radios are centralized or distributed configured, radios are treated as independent processing units under the joint working mode. The optimal beam forming weights will be carried out by each node individually in distributed manner, which also distributes the calculation over all nodes. The optimum can be iteratively reached in some cases. This also put forward requirements to the information sharing among radio nodes.

**Influence of Frequency Hopping Mode**

Working frequency change will affect beamforming performance. The existing researches always treat frequency hopping system as fix-frequency system in frequency hopping interval [10], and calculate the beamforming weight under the current frequency. Once working frequency changes, the beamforming weight will be calculated again. In order to catch up with frequency change rate, these approaches require fast computing speed, low and limited computational complexity. It will get harder to realize weight computing in fast FH system. One research direction is to propose new methods which can take advantage of the frequency hopping mode to reduce computation.

**Synchronization**

Every radio node has its own local oscillator and clock circuit. Before beamforming, we have to deal with time, frequency and phase offsets and errors, which also can affect the beamforming performance [11]. The carrier synchronization can be reached by direct synchronization algorithm or through changes in the calculated weights at each node.

**Simulink Results and Analysis**

Here we design a Simulink experiment to illustrate the effectiveness of the three joint working methods using multiple antenna technology.

Suppose that both the transmitter and the receiver are employed with uniformly linear array (ULA) with \(\frac{\lambda}{2}\) inter-element spacing, where \(\lambda\) denotes the wavelength. The carrier frequency is 60MHz. The receiver locates at the far field. Three cases are simulated here.

Case1 jointly transmit scenario. The transmit beamformer is designed with Semidefinite Programming (SDP) algorithm under total transmit power constrain. The look direction of a target is 30°.

Case2 jointly receive scenario. The DOA of the target of interest is 30°, while the DOAs of two interferences are \(-15°, 45°\). MVDR beamformer is employed here to realize receive beamforming.

Case3 jointly transmit and receive scenario. In this case, the look and receive angles are 30°, while the DOAs of two interferences are \(-15°, 45°\). The transmit beamformer and the receive beamformer are jointly designed.

Beampatterns in each case are shown in Fig. 4. As mentioned before, the three methods adopt different principle to realize interference suppression, which is also verified by the Simulink results. In jointly transmit method, our main target is getting mainbeam toward the receiver as shown in Figure 4(a). In jointly receive method as shown in Figure 4(b), the mainbeam points to the angle of interest signal and nulls point to the DOAs of the interference signals. As shown in Figure 4(c) and
4(d), we can realize beamforming at transmit and receive end. But there are mutual influences between the two beamformer, which leads to the different performance in beampattern. Although we can get better interference suppression performance in this case, the computing burden is higher. In all three cases, we can get better beampattern with improved algorithm.

![Beampattern](image)

(a) Transmit beampattern in jointly transmit  
(b) Receive beampattern in jointly receive

(c) Transmit beampattern in jointly transmit and receive  
(d) Receive beampattern in jointly transmit and receive

Figure 4. Beampattern in each case.

**Conclusion**

Drawing on the cooperative work idea, multiple FH radios joint working mode for interference suppression occasion is discussed here. The mode can be used to ensure normal communication under emergency occasion at the price of additional hardware and signal processing. Three kinds of joint working mode realization by means of array information processing technology are analyzed here. There remains challenges need to be solved in future research.

**References**


