A New Anti-Jamming Method Combining Adaptive Array Antennas and Frequency-Hopping Techniques

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***Abstract*— A new method of multi-hopping data blocks blind beam-forming is presented based on combining adaptive arrays and frequency-hopping techniques. This method makes use of the different characteristics of frequency-hopping signal and jamming after they are de-hopped. The simulation results show that varied jamming threatening frequency-hopping systems can be eliminated effectively.**

***Keywords*— frequency-hopping intermittent jamming follower jamming adaptive array LS-CMA**

I. Introduction

Satellite communication systems employ a variety of techniques to achieve acceptable protection against jamming. Adaptive array antenna processing and frequency hopping are the two most powerful techniques for jamming rejection. The former makes use of its ability of spatial discrimination to achieve jamming rejection. But when the DOA of signal and jamming is adjacent closely, the performance of this technique would reduce dramatically. The later using the different frequency characteristic of signal and jamming provides a high immunity against jamming, whether it is intentional or not. However, the performance of this technique can be severely degraded in the presence of an "intermitten" blinking jammer [1], that is, a jammer that is present for only a fraction of the time or frequency. A satellite communication system that combining frequency hopping and an adaptive array antenna has enormous potential for jamming suppression. The total processing gain is at least approximately equal to the sum of the individual processing gains.

Jorgensen [2] has given an anti-jamming method combining adaptive nulling antenna and frequency hopping, which is composed of two stages. Each one eliminates different jamming, such as comb jamming, intermittent jamming and so on. Obviously, this method using different beamforming compacting different jamming complicates the problem. Eken [3] proposed another beamforming method to eliminate jamming which is based on the different reaching time of signal and jamming. This method is powerful to compact coherent jamming. Changzhen Chen [4] also gave a method to eliminate following jamming. However, it is difficult to realize in practice because of its limitation, that is, the whole processes have to be finished during one hopping internal. And also, not all kinds of jamming are considered.

Herein, based on deeply researching on the characteristics of hopping signal and jamming, we purpose a new method combining adaptive array antenna and hopping frequency techniques to compact jamming. We called multi-hopping data block blind beamforming. The merit of this method is that jamming can be eliminated just by using one algorithm. Numerical simulations illustrate the feasibility of our method.

The rest of the paper is organized as follows. Various jamming which is threatening hopping signal is introduced in section II. In section III, the data model is presented, we will find that different kinds of jamming can come down to a same model in a hopping frequency system. The constant modulus characteristics of hopping signal and jamming is discussed in this section. In section IV, we introduced the Least Squares Constant Algorithm (LSCMA) in detail. The system simulation and the simulation results analysis are presented in section V. Finally, section VI concludes the paper.

II. Jamming Mode Threatening Hopping

In a hopping frequency spread spectrum system, the signal of interest (SOI) is hopping in the whole system bandwidth. That is to say, we eliminate intentional jamming in an "evading" way. Jamming is effective just only in the hopping frequency point. Among the various jamming strategies threatening hopping frequency signal, there are well known modes, such as is full band jamming, partial band jamming, follower jamming, multi-tone jamming and so on[5].

Full band jamming can be modeled by band-limited white gauss noise. Because its power spectrum density covered the

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whole bandwidth, this kind of jamming is equivalent to increasing the noise level of receiver.

(BER) of receiver will be in inverse ratio to the input signal to jamming ratio (SIR), resulting in an extremely dropping of system performance. Partial band jamming include partial band noise jamming (PBNJ) and partial band tone jamming (PBTJ). Because of its hopping in the whole bandwidth, SOI will hop in and out of the band area where there is partial band jamming, resulting in the jamming being present during some hop intervals and absent in others. We may call this characteristic as intermittence. Thus, generally, jamming with such a characteristic is called intermittent jamming. Comb jamming may be regarded as an utmost shape where SOI hop in the jamming band all the time.

Another type of interference is follower jamming. Jammer can intercept and capture SOI. After being modeled and amplified, the SOI will be transmitted at the same centre frequency again. In order to track the hopping frequency system, interference must reach the target receiver before SOI hopped to a new frequency point. A remedy for this type of jamming is to hop faster. By doing so the jammer will become less effective due to the time delay in its response to a frequency hop caused both by the propagation delay and the jammer processing time, although at first, fast hopping can be seen to be the solution to the follower jammer threat, it has the potential disadvantages of high implementation cost and interference to other users of the band. We note that Differing from above intermittent jamming, follower jamming exits in each hop of SOI and gets activated sometime after the frequency hop occurs. Repeat back jamming also has such a characteristic.

From above analysis, we know that, hopping signal (SOI) exists in each hop. Thus its characteristic such as constant modulus (CM) can be held after de-hopping, While, no matter whether or not the intermittent jamming is CM, it will be un-CM after de-hopping because it appears in a hop randomly (jamming is intermittent after de-hopping as we analysis above). As for follower jamming, it appears only in the tail part of each hop. Thus no matter which type is the jamming, it will not be CM after de-hopping. This paper proposes a new solution to realize interference elimination by using antenna nulling and the different characteristics between SOI and jamming after de-hopping.

III. DATA MODEL AND NULLING ALGORITHM

In this section, we introduce the model used throughout the paper, this main motivation stems from the study of a frequency-hopping satellite communication system. Firstly, we assume interference is intermittent (such as partial band jamming with a bandwidth B_j), which occupies a fraction of the total bandwidth and can be briefly described by Fig.1, even though this model is not restricted to this particular

Partial band jamming is most threatening to hopping signal. Especially, when this kind of jamming is design in an appropriate jamming to bandwidth ratio, the bit error rate case. We assume that one signal of interest is hopping inside a bandwidth B_t centered round some frequency f_c. We let B denote the instantaneous bandwidth occupied by SOI. We assume the total bandwidth in which the SOI hop is only a small fraction of the center frequency, say, a few percent (hence, B_t / f_c is small). Depending on the position of the frequency hop, the interference will be present in some hops and absent in others. We assume that the two signals impinge on a uniform linear array of m sensors. Then, the complex envelop of the received signal can be the models for: $k = 0,......,K-1$; $n = 1,......,T$ as[1]

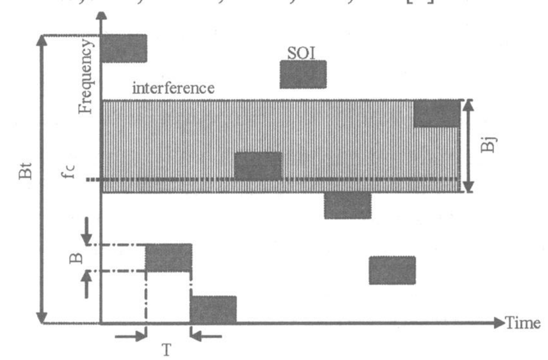

Fig. 1 frequency-hopping system with intermitten interference

$$x(kT+n) = s(kT+n)a(\theta_s) + \mu_k s_j(kT+n)a(\theta_j) + N(kT+n) \quad (1)$$

Here, $k = 0,......,K-1$ denotes the kth hop, $n = 1,......,T$ denotes the nth sampling data in one hop interval. T is hopping period. $s(t)$ [resp. $s_j(t)$] is the complex envelope of the signal [resp. jamming]. It is assumed that $s(t)$ and $s_j(t)$ are mutually independent identically $a(\theta) = \left[1 e^{i(2\pi d f_c/c)\sin\theta} \ldots e^{i(2\pi d f_c/c)(m-1)\sin\theta}\right]^T$ is array response to a source impinging from direction θ, and d is the inter-element spacing. Here we assume that the total bandwidth in which the signal hops is negligible compared with the center frequency. the noise $n(t)$ is zero mean, Gaussian distributed, spatially and temporally white with covariance matrix $\sigma^2 I$ $\mu_k \in \{0,1\}$ is an indicator of the presence of the jamming in the kth hopping interval. Hence, it is assumed that the jammer is present for at least T consecutive snapshots but can be turned "on" and "off" each T snapshots (we do not consider the case where some of the $\mu_k s$ could vary within the kth hopping interval).the limiting case T=1corresponds to a jamming that could possibly appear and disappear at each new snapshot. We assume here that T is known (for example, T may correspond to the hop duration in Fig.1). μ_k is unknown. Thus we can model it as a sequence of independent discrete random variables taking values in the set $\{0,1\}$ with probability $1-p$ and p, respectively. Doing so, the dimension of the parameter space is reduced. However, a priori information is required; more precisely, p has to be known [or at least guessed, which would result in a loss of robustness]. Obviously, p can be regarded as appearance probability of jamming (or called impinging rate). As for the intermittent jamming, it presents the ratio of jamming bandwidth to the whole hopping bandwidth.

We assume follower jamming didn't occur at the beginning. Then, μ_k (here, μ_k can be replaced by μ_{kn}, $n=1\cdots N$)would be 0. When follower jamming appears during a hop, μ_{kn} would be 1. Moreover, it only occurs in the hind side of the jammed hop (generally, jammer used the front side of the hop interval to capture, analyze and process the SOI). Without loss of generality, if we assume follower jamming occurs in hind side of the kth hop interval, we will have. $\mu_k=\left(\overbrace{0\cdots0}^{(1-p)N},\overbrace{1\cdots1}^{pN}\right)$.

From above analysis, we can find that no matter which kind of interference, the received data model can be consolidated into one form. The only difference is the choice of its parameter μ_k. This model is simple, yet flexible enough. Although it does mot include all possible jamming configurations, it is representative of most situations. Moreover, its simplicity allows for rather straightforward derivations and, thus, provides insights into the problem.

This data model indicates that SOI always exists after de-hopping while interference (except comb jamming) appears intermittently. In fact, this is the result of frequency-hopping modulation. This phenomenon is very important for us, because, usually, modulated signals in digital communications character Constant Modulus (such as MFSK DQPSK and so on). That is to say, signals have a constant envelop. As for a block of received data, SOI's CM characteristic would be held after de-hopping. While no matter whether or not the jamming is CM, it will always be un-CM after de-hopping because of its intermittence. It suggests that we can use Constant Modulus Algorithm (CMA) to realize interference elimination in hopping frequency systems. In next section, we will indicate that Least Square Constant Modulus Algorithm (LSCMA) is the best choice because of its block-update iteration

Constant Modulus Algorithms can be used for adaptive beamforming, equalization, and other applications when the desired signal has a constant envelop. Examples of such signals include FM, PSK, and FSK. The CMA can also be applied to many non-CM signals although the performance may be degraded. The main advantage of CMA is that it is a "blind" adaptive algorithm, i.e., is does not require a training signal. The main drawback of this method is its slow convergence. Least Squares CMA [6] is a fast converging CMA, which is a block-update iterative algorithm. It is guaranteed to be stable and is easily implemented. Because of length limitation of the paper, We introduce it simply as below.

At the kth iteration, N temporal samples of the beamformer output are generated using the current weight vector w_k. This gives

$$y_k(n)=w_k^H x(n) \tag{2}$$

The kth signal estimate is then hard limited to yield $d_k(n)=\dfrac{y_k(n)}{|y_k(n)|}$ and a new weight vector is formed according to $w_{k+1}=R_{xx}^{-1}r_{xd}$. where $R_{xx}=\left\langle x(n)x^H(n)\right\rangle_N, r_{xd}=\left\langle x(n)d^H(n)\right\rangle_N$

The iteration is continued until either the change in the weight vector is smaller than some threshold, or until the envelop variance of the out put signal is deemed sufficiently small. The LSCMA iteration can be reapplied to the same block of observed data, or can be performed using a new block of data. The former approach is referred to as static LSCMA, while the latter approach is referred to as dynamic LSCMA.

Combining above analysis about hopping frequency data and LSCMA, we propose a new interference elimination method as follow. Adaptive array receiver samples the de-hopped arrival signal to form multiple channels sampled signal. These signals compose a data block as the input of beam-former. In the case where there are only SOI, LSCMA converge at SOI rapidly. When jamming appears, because of its non-CM characteristic, beam-former null the jamming and keep the optimal receive to SOI. Here, data block processing has two important effects. One is that block–update algorithm has a rapid convergence. The other is that the signal information not only in current hop, but in the history, hops are included in the data block.

Obviously, dynamic LSCMA rather than static LSCMA is applied in our method. It is because of the undated iteration with new data block that beamformer can track the variety of signal environment. So that once interference appears, it can be eliminated rapidly.

IV. PERFORMANCE SIMULATION

Performances of the method described in above sections are evaluated by computer simulation. Uniform linear array with 7elements are used in our simulation, the space between elements is 0.5λ. Hopping signal is 2FSK signal with symbol rate $F_d = 4.8kHz$, frequency interval $\Delta f = 4.8kHz$, signal to noise ratio $SNR = 10dB$ and direction of arrival $DOA = 0^0$. It is assumed that interference to noise ratio (INR) of the jamming is 30dB with $DOA = 30^0$. Here, we define DOA as the angel between direction of signal and normal direction of the array. Simply, we assume sampling rate is $8 \times F_d$, and hopping rate is F_d. Fig. 2~Fig.5 bellow are the output performance curves of signal interference to noise ratio (SINR) to iteration with different kind of jamming, respectively (intermittent noise jamming, intermittent swept jamming, follower noise jamming and follower single tone jamming). These figures indicate that no matter which kind of jamming and whether or not it is CM, LSCMA beamformer can keep the output SINR up to 10dB and eliminate jamming effectively. With the increase of p in intermittent jamming cases and the decrease in follower jamming cases, the curves converge decreasingly. Here, p is defined as above analysis. In Fig. 2, $p = 100\%$ denotes the case of full band jamming which converges slowly. In Fig. 3, with the increase of p, the curve will not converge at all. In fact, this case occurs hardly in practice because the jammer must cost more extremely.

V. CONCLUSION

Adaptive array technique and hopping frequency technique are the two important methods to improve the anti-jamming capability in the satellite communication system. The combining of these two techniques can remedy their shortage each other so that improve the integrated anti-jamming capability. Based on the analysis to the different characteristic of hopping signal and interference, this paper proposed a new anti-jamming method, named, multi-hop data block blind beamforming. This method operates de-hop before nulling and is independent on the DOA of signal and training sequence because of the CM characteristic of hopping signal. The simulation indicate that this method is effective to eliminate any kind of jamming that threat the hopping frequency system, such as full band jamming, partial band jamming, multi-tone jamming, follower jamming and so on. Moreover, considering the de-hopping as a whole process on board, that is, using one de-hopper processes multi-channel signals, this method can be extended to multi-user blind beamforming process.

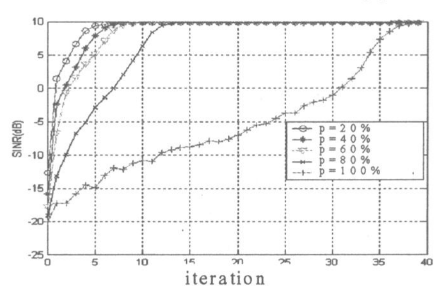

Fig. 2 SINR as a function of iteration with Intermittent noise jamming

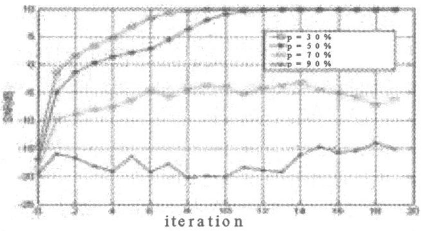

Fig. 3 SINR with intermittent scanning frequency jamming.

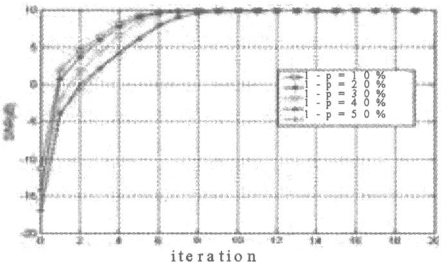

Fig. 4 SINR with Follower noise jamming

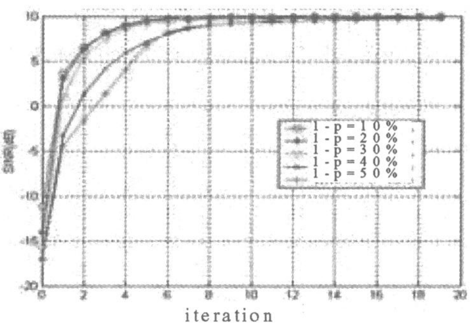

Fig. 5 SINR with follower single-tone hamming

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