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To cite this article: Yadong Zhao *et al* 2020 *J. Phys.: Conf. Ser.* **1584** 012037

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Design of Wide Interval Frequency Hopping Pattern for Frequency Hopping Mobile Ad-hoc Networks

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Abstract. The frequency hopping mobile ad-hoc network (FH MANET) is a communication network that combines frequency hopping (FH) technology and mobile ad-hoc network (MANET) technology. FH technology can improve the anti-interference performance of the network, and MANET technology improves the mobility and anti-destructiveness of the network. It can be networked autonomously without manual intervention and other network facilities. It has strong application value in complex battlefield environment and occasions with harsh environment and high confidentiality requirements. The frequency hopping pattern (FHP) design is a key technology in the FH MANET, which is directly related to the network's anti-interference and multipath fading capabilities. In this paper, a wide interval expansion method (WIEBM) based on m-sequence and non-continuous tap L-G model is proposed. The experimental results demonstrate that proposed scheme can effectively improve the anti-interference ability of the system. It has the ability to resist more than 30% of broadband interference.

1. Introduction

A frequency hopping mobile ad-hoc network (FH MANET) consists of multiple special nodes. It can complete the self-organization of the network and realize specific network functions through information interaction. Nodes can join or leave the network at any time without infrastructure support. At the same time, the data is transmitted in frequency hopping (FH) mode to improve the system's anti-interference, anti-interception and confidentiality capabilities. Therefore, it has a wide range of applications in military, confidential occasions and harsh conditions. For the frequency hopping system with frequency hopping rate determination, designing the hopping sequence to a wide hopping interval can more effectively combat narrowband interference, tracking interference and broadband blocking interference, and multipath fading [1]. Therefore, the design of frequency hopping pattern (FHP) has become one of the important issues in the study of FH MANET systems.

At present, there are mainly the following methods for the designing of wide-interval FHP. The de-intermediate frequency band method proposed in [2]. The disadvantages are: low frequency hopping patterns, poor randomness and poor anti-decipherability. Fuming Hong and Shiping Zhang proposed the dual band (DB) method in [3]. The DB method is much better than the de-intermediate frequency band method, but the randomness and confidentiality are still not high. Reference [4] proposed three methods for constructing a family of wide-interval hopping sequences based on a family of prime



sequences. Reference [5] describes a new class of methods based on the DB method and the L-G model to construct a family of wide-interval hopping sequences. Reference [6] proposed the WIDBS method. The performance of the generated sequence is significantly improved compared to the DB method. A random translation alternative method is proposed in [7]. A class of improved random translation alternatives constructed by wide-interval hopping sequences was introduced in [8]. In [9], a new method for constructing chaotic wide-interval hopping sequences is proposed. In [10], the chaotic-based hopping sequences are widely spaced by the circular band method and the DB method. The results of the anti-interference ability of the two are obtained under different application backgrounds.

The scenario in this paper is a FH MANET, which has its particularity. First, the working frequency band and channel bandwidth requirements are fixed. Second, the system uses TDMA (Time Division Multiple Access). Considering that the m-sequence has the characteristics of simple implementation and good correlation, this paper uses the non-continuous tap L-G model based on m sequence. In this scenario, there are maximum frequency value and minimum frequency value, which can also be understood as a fixed number of frequencies. In this paper, we select the DB and the WIDBS methods, which are based on m sequence and have representative, for comparative analysis. On one hand, there are upper limits for the pattern interval designed by the above methods. The maximum interval is $q/4$, where q is the number of frequencies. On the other hand, since the frequency hopping self-organizing network adopts the TDMA method, it belongs to the synchronous system. The advantages of the WIDBS method in auto-correlation and cross-correlation will also be greatly weakened, because the auto-correlation and cross-correlation factors have little effect on the synchronous system. Therefore, the interval parameter and the balance characteristic become the main considerations. This paper proposes a method -- wide interval expansion method (WIEBM) to increase the frequency hopping pattern spacing, so that the system's anti-broadband interference capability is more than 30%.

The remainder of this paper is organized as follows. Section II presents WIEBM principle and theoretical analysis. Simulation results of the proposed method compared with DB and WIDBS method are introduced in Section III. The conclusions are drawn in Section V.

2. WIEBM principle and theoretical analysis

In this paper, the non-continuous tap L-G model based on m sequence is used to generate the hopping sequence. The m sequence generator employs n-level on the finite field $GF(2)$. As shown in Figure 1. Details can be found in [8].

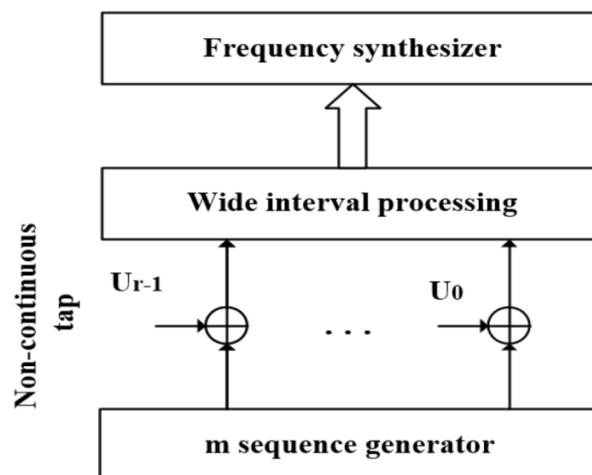


Figure 1. M-sequence based on non-continuous tap L-G model.

In Figure 1, $U = (U_{r-1}, \dots, U_0)$ indicates the user taps. Using the discontinuous tap L-G model, r ($r \leq n$) stages are optionally selected from the n -level shift registers, which can form C_{n-1}^{r-1} sequences.

WIEBM method: A set of frequencies generated on a given bandwidth B is $f = \{f(k) | 0 \leq k \leq q - 1\}$, where q is the frequency number. Let F be a cycle length hopping sequence, $F(i)$ is the i^{th} hopping sequence element, $i = 1, 2, \dots, 2^n - 1$. For F , if $|F(i+1) - F(i)| \geq d + 1$, it means that the frequency hopping interval of the F sequence is d , and F is called a wide interval hopping sequence.

WIEBM principle:

1: If $|F(i+1) - F(i)| \geq d + 1$, then

$$F(i+1) = F(i+1).$$

2: When $d < q/2$:

If $|F(i+1) - F(i)| < d + 1$, then

$$F(i+1) = (F(i+1) + d + 1) \bmod q,$$

If $|F(i+1) - F(i)| < d + 1$, then

$$F(i+1) = (F(i+1) + d + 1) \bmod q,$$

Cycle through 2 until:

$|F(i+1) - F(i)| \geq d + 1$, then

$$F(i+1) = F(i+1).$$

3: When $d \geq q/2$, WIEBM principle will not meet the frequency interval requirement.

An example is as follows:

The frequency number q is 16. The frequency interval d is 5. The WIEBM scheme can be mapped to the table 1:

Table 1. Frequency mapping table of the WIEBM scheme

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	7	8	9	10	11	12	13	14	15	0	1	2	3	4	5
12	13	14	15	0	1	2	3	4	5	6	7	8	9	10	11
2	3	4	5	6	7	8	9	10	11	12	13	14	15	0	1
8	9	10	11	12	13	14	15	0	1	2	3	4	5	6	7

1. Suppose $F(i) = 5$, $F(i+1) = 11$, as $|F(i+1) - F(i)| \geq d + 1$, then $F(i+1) = 10$.

2. Suppose $F(i) = 5$, $F(i+1) = 4$, as $|F(i+1) - F(i)| < d + 1$, then $F(i+1) = (F(i+1) + 6) \bmod 16 = 10$,

as $|F(i+1) - F(i)| < d + 1$, then $F(i+1) = (F(i+1) + 6) \bmod 16 = 0$,

as $|F(i+1) - F(i)| < d + 1$, then $F(i+1) = (F(i+1) + 6) \bmod 16 = 6$,

as $|F(i+1) - F(i)| < d + 1$, then $F(i+1) = (F(i+1) + 6) \bmod 16 = 12$,

as $|F(i+1) - F(i)| \geq d + 1$, then $F(i+1) = 12$.

3. Simulation results

In this section, we present simulation results to illustrate the performance of the proposed scheme. The simulation parameters are set as follows. The shift register is n bits. The number of frequencies is q . The sequence length L is $2^n - 1$. The users tap U defaults to all 0. The non-continuous tap $r = [0, 2, 4,$

6]. The frequency interval is d , $d \in [1, q/2 - 1]$. The balance parameter $\sigma = \frac{q}{L} \sqrt{\frac{1}{q} \sum_{i=0}^{q-1} (g(i) - \frac{L}{q})^2}$,

where $g(i)$ is the number of times of the i^{th} frequency $F(i)$ in a frequency hopping cycle. Ideally, $g(i) = L/q$, ie $\sigma = 0$. The closer σ is to 0, the better the balance and the more uniform the frequency distribution. The average hopping interval is defined as average interval between two consecutive hopping frequencies. The WIEBM, WIDBS and DB were compared in the simulation.

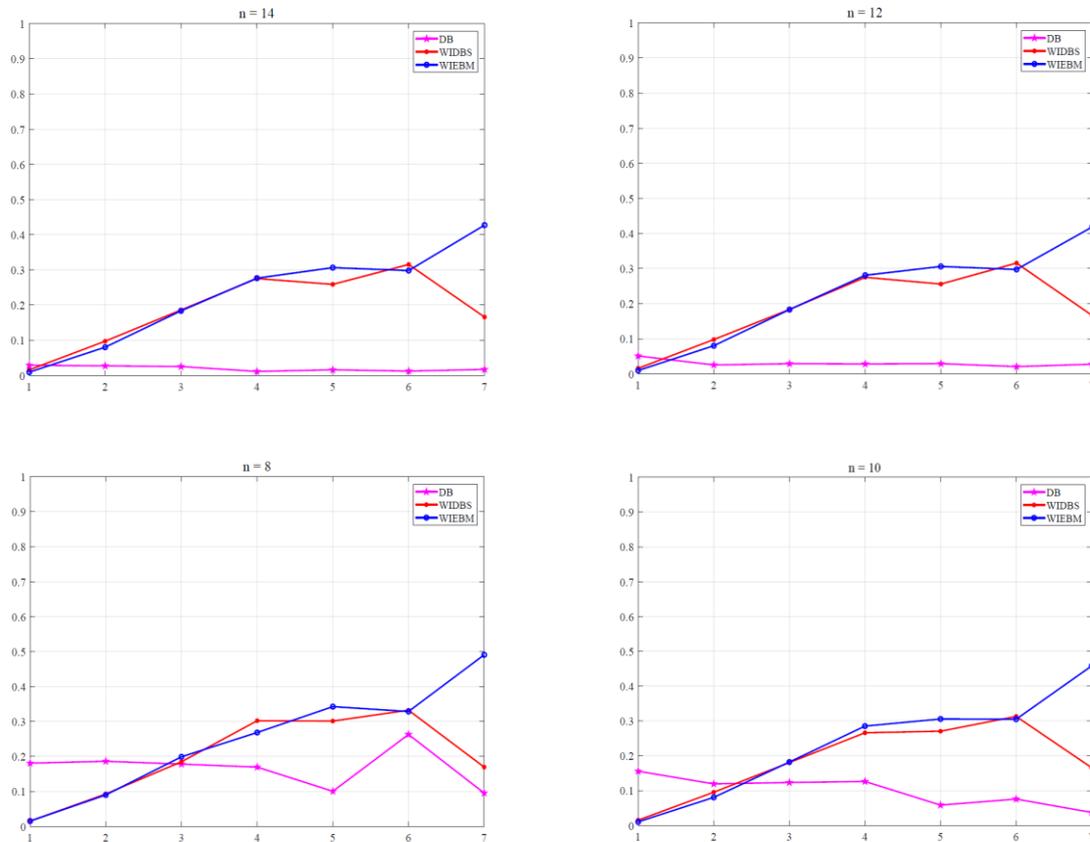


Figure 2. The balance parameters for the three methods at different intervals.

In Figure 2, we show the balance parameters for the three methods at different intervals when the number of frequencies q is 16. As shown in the figure, with the increase of n , WIEBM and WIDBS are basically the same and the balance characteristic increase. Both of them are bigger than the DB method. The closer σ is to 0, the better the balance and the more uniform the frequency distribution. So the DB method is the best.

Figure 3 presents the minimum spacing of the three methods. The shift register n is 8. The frequency number q is 16. As shown in Figure 4, with the frequency interval increasing, the minimum interval of the WIEBM increases and the WIDBS and DB methods begin to rise and then fall. It shows that WIEBM has a larger frequency interval. Because all frequency intervals of the WIEBM method meet the interval requirements, while the other two methods have frequencies that do not meet the interval requirements. From this perspective, the anti-interference ability of WIDBS and DB method is about $4/16=25\%$, and the anti-interference ability of WIEBM can reach $5/16=31.25\%$ or even higher.

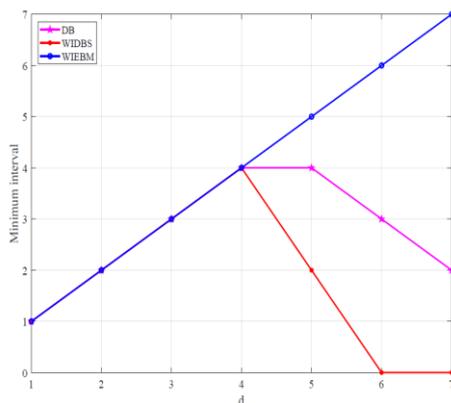


Figure 3. The minimum spacing for the three methods.

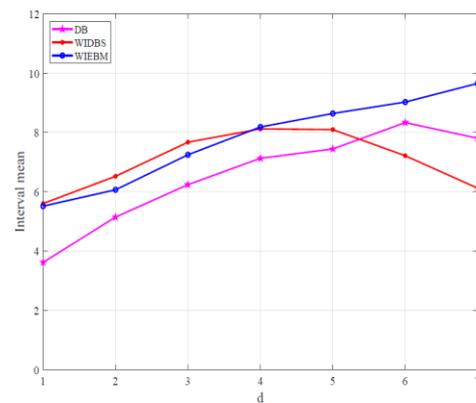


Figure 4. The average spacing for the three methods.

Figure 4 compares the average spacing for the three methods. The shift register n is 8. The frequency number q is 16. As shown in the figure, with the frequency interval increasing, the average interval of WIEBM increases, however, WIDBS and DB methods begin to rise and then fall. It shows that WIEBM has a good mean value of frequency interval. This also confirms that WIEBM has a stronger anti-interference ability compared to WIDBS and DB methods.

4. Conclusion

In this paper, considering the scene of a FH MANET system, based on the non-continuous tap L-G model and m-sequence, we applied the WIEBM method for generating FHP. Simulation results show that the proposed method is superior to WIDBS and DB methods in frequency interval. Although there is an upper limit of the frequency interval, the WIEBM scheme breaks through the upper limits of the two other methods and improves the anti-interference ability of the system. We can also see that these parameters are mutually constrained, so a suitable solution must be adopted according to the actual needs. This program has practical guiding significance.

Acknowledgement

This work was supported in part by National Natural Science Foundation of China (Grant No. 91738202), partly by National Natural Science Foundation of China (Grant No. 61790553) and partly by Shenzhen science and technology plan projects (JCYJ2018030617061448).

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