Analysis of multiple users communication based on Time and Frequency-Hopping system and its implementation

Xu Zheng[1, a], Weichao Pi[2, b,*], Xi Yan[2, c], Xingwang Li[2, d], and Sunying Fei[1, e]

[1]School of Electronic, Electrical and Communication Engineering, University of Chinese Academy of Sciences, Beijing 101400, China

[2]School of Information and Electronics, Beijing Institute of Technology, Beijing 100081, China

[a]xuzheng292@163.com, [b]peao_kelvin@bit.edu.cn, [c]2120160702@bit.edu.cn, [d]xw_lee93@163.com, [e]yfsun@ucas.ac.cn

*Corresponding author

Keywords: time and frequency hoping, analysis, implementatio

Abstract: As is well-known, the frequency hopping system may have a serious collision problem with the increase of the number of users. Thus a more fast frequency hopping strategy is required to enhanced the collision performance and lead to a higher requirement for frequency hopping rate. In this paper, to overcome this problem a framework of time and frequency system was introduced to satisfied the requirement. The performance of time and frequency-hopping (TH-FH) system for multiple users communication was investigated firstly and then the simulation and measurement results were shown to prove the effectiveness. Based on the frame structure and hopping radio frequency framework the network access with much lower collision probability for multiple users can be realized.

1. Introduction

Because of sharing the advantage of low mutual interference and anti-jamming capability, the frequency-hopping (FH) technique has been widely used in communication, navigation and radar system [1, 2].

The most typical application of the FH system is that multiple users communicate in FH multiple-access (FHMA) network. The asynchronous FHMA network is widely used because it has no special requirements for the network clock and has high capability of antagonizing blocking jamming. But unfortunately, with the increase of the number of the user, the collision will become much more serious to reconstruct the data. Moreover, in the practical application, the shortage of available frequency slot will be another probability. And FH system also shares the risk of being detected by frequency surveillance devices and thus, it needs more improvements.

Time hoping technique is available to alleviate this problem without any critical modification [3, 4]. The most successful application of time hoping access system is the TDMA communication. Different user was authorized with certain time slot, thus decreasing the mutual interference in the network. So, combing the advantages of TH and FH technique, there might be greater improvement on the communication efficiency and frequency jamming avoidance simultaneously.

This paper is divided into several parts as follows: Section II of this paper analyze the performance of TH. Section III introduces a framework of TH and FH system. In the Section IV shows the implementation and measurement results with discussion. At last the conclusion is given.

2. System Model of Time and Frequency Hopping Network

2.1 Time hopping model

Time hopping model is shown in the following figure and classical TDMA in the second generation mobile communication system is the best example. The transmit signal is only radiate at the authorized discrete time pulse intervals or time slot and the transmit time slot is only decided by time hopping sequence generated by different hopping algorithm. Obviously, the greater number of time slot is the less probability of collision will occur but unfortunately thus will confront the longer time of signal processing period.

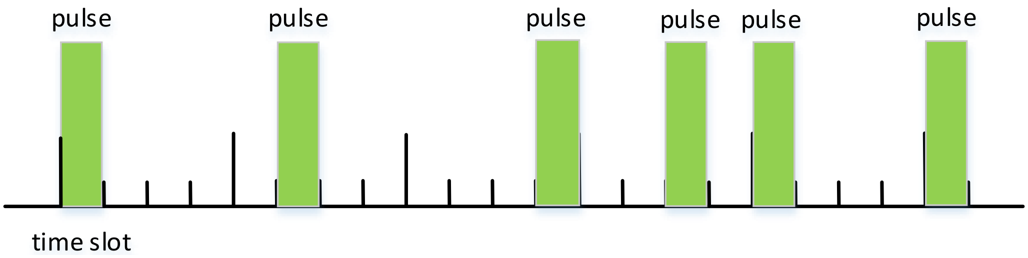


Figure 1. Time hopping model

2.2 Continuous frequency hopping model

The network established without center node by multiple users with asynchronous access and make the following hypothesis as follow.

- The network, with multiple FH users denoted as User i, are accessed by multiple users, and each user could transmit packets stochastically and independently.
- According to each user, to avoid being interfered by other user, system generate hopping frequency pattern at different time from an available set H consisted of q different frequency slot.

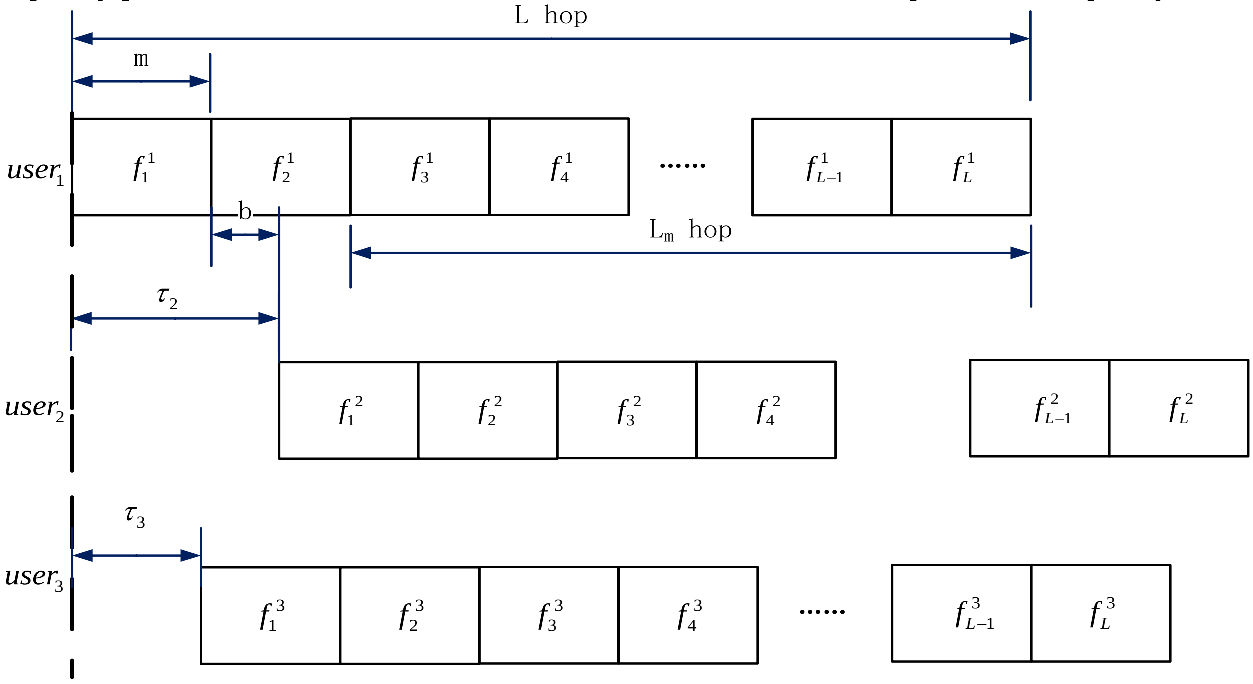


Figure 2. FHMA model

The continuous frequency hopping model is discussed with detail in [5, 6] and our previous work [7]. Here we give the simulation of this model in some scenario with practical parameters. Assuming user number is U, hopping number is L and the erasure correction parameter of channel decoding is α, Let α=0.2, $L=20$, $m=300$ are fixed parameters and the number of hopping frequency slot q varies from 20 to 64 with increment of 4, the results are shown in Fig. 3 with different frequency hopping sequence method[8, 9].

Obviously, with the decrease of L the collision ratio increase remarkably and the number of q should be at least 10 times more than the number of users in the network, otherwise the performance will deteriorate significantly. But in the actually application, the available frequency slot may much smaller than system design, that means the performance of network will be attacked to breakdown easily in the practical application.

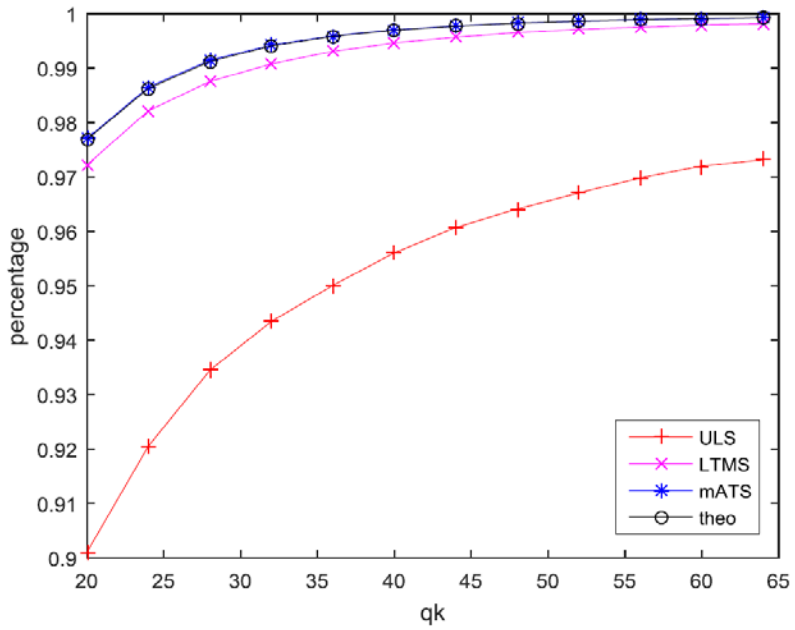


Figure 3. FH performance for different frequency slot

2.3 Time and frequency hopping model

The time hopping and frequency hopping mode is shown in Fig. 4. To compress the length of time duration and avoid the appearance of 3D graphic, we take the different time slot at the y axis and different frequency slot is presented with various colors. Thus data from each user was discrete into different time slot and frequency slot resource unit in a rectangular form and it is also equal to a cubic form without color of frequency slot.

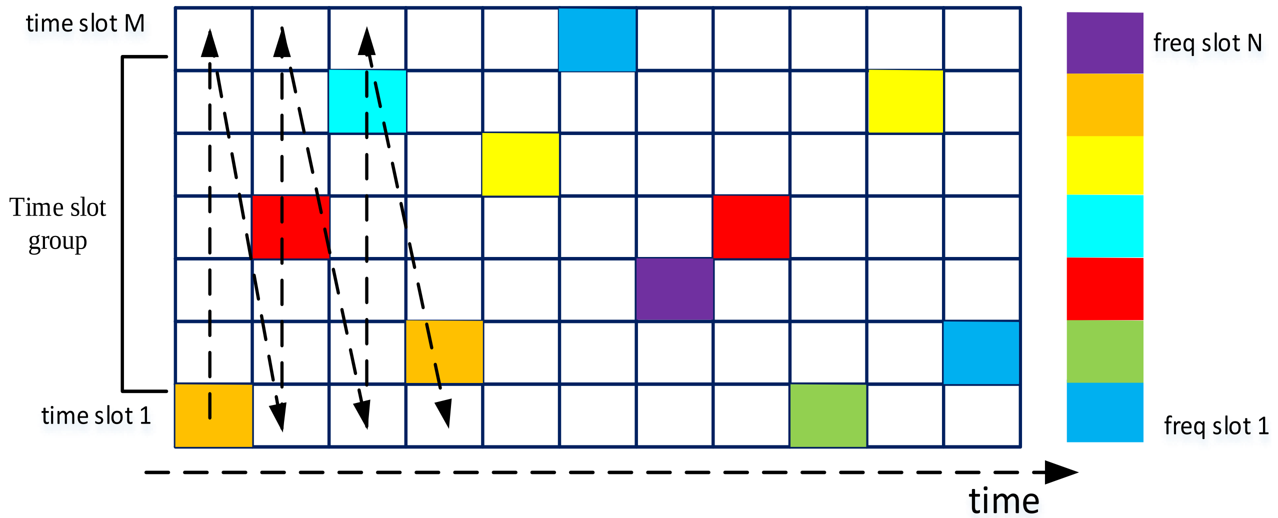


Figure 4. Time Hopping And Frequency Hopping Model

To simplify the figure, here we take two users as an example. As is shown in the, symbol τ represents the time delay of User2 's packet relative to User1 's. ML means the total time of one frame, t_j^i means the selected time slot of jth slot time group from the set of time slot in total of M. f_k^i means the frequency slot at the kth time interval for the ith user.

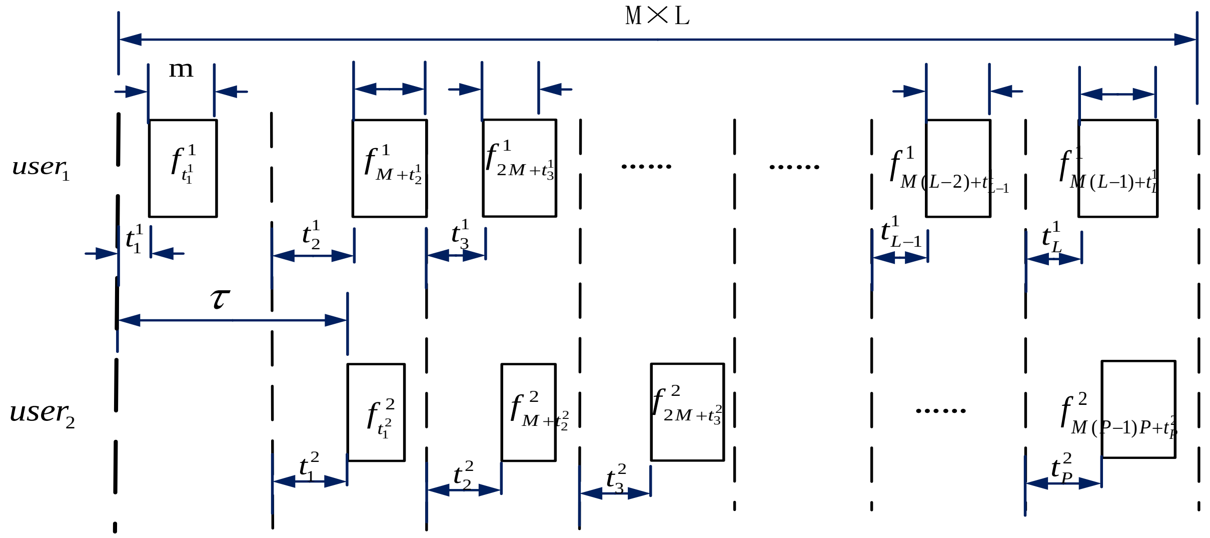


Figure 5. Time Hopping And Frequency Hopping Model for two users

Obviously, the TH and FH model is more complicated than the multiple frequency hopping model, to further use the results of frequency hopping model, here we introduce the extra frequency slot, f_{out}, to represent the slot time which has not been used in a time slot group, thus the TH-FH model could be convert back to a no uniform frequency hopping model as is shown in Fig. 6, the time slot is filled with frequency slot or the symbol f_{out}.

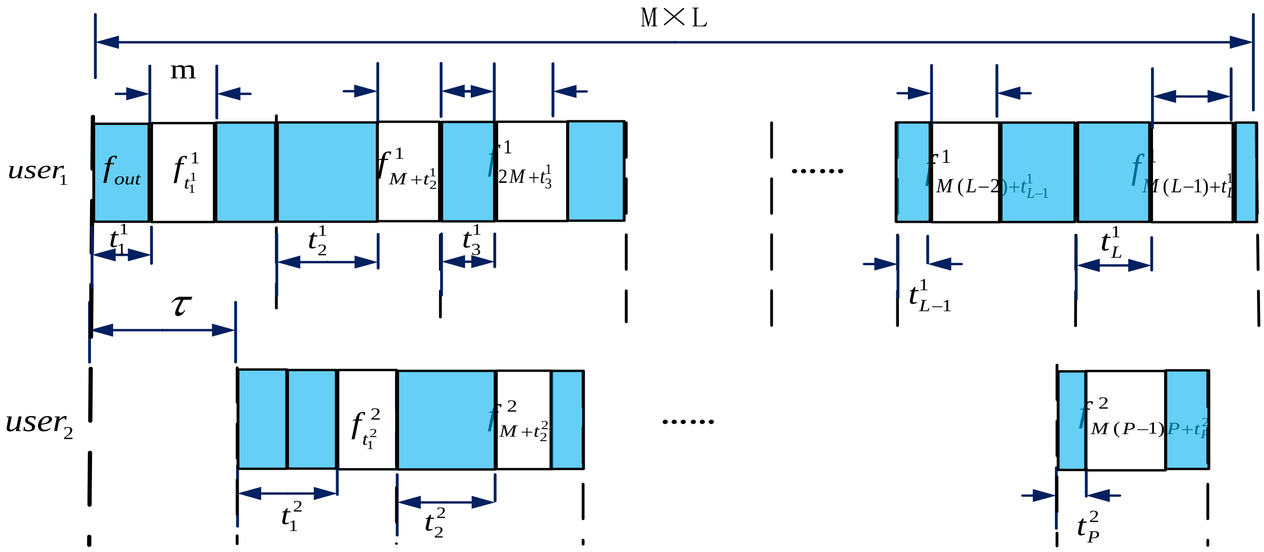


Figure 6. Equivalent Frequency Hopping Model for two users of time and frequency hopping model

As the only one frequency slot paired to certain user during a time slot group, thus the probability of the frequency slot and f_{out} satisfy the following the expression for a certain user at a slot group interval, Here M and N mean the total number of time and frequency slot. Symbol" $\rightarrow$ "means convergence in probability

$$p\{f = f_i\} \rightarrow \frac{1}{MN}, i \in 1,\ldots,N, f_i \in f_{slot}$$

$$p\{f = f_{out}\} \rightarrow \frac{M-1}{M}$$

The collision of the two group with same frequency pair is $p \rightarrow \frac{1}{M^2 N}$,

If consider the equivalent frequency hopping model, the frequency collision will only happen as the frequency slots of different user equal at same time ,but the exclusion of existence of f_{out}, here we give the two user collision expression as following equation. the $P_{nc\tau}(\tau=\tau_0)$ represents the total collision number of bits with the time delay of τ_0 between two users,

$$P_{nc}=\frac{1}{MLm}\sum_{\tau_0=0}^{MLm}P_{nc\tau}(\tau=\tau_0)\cdot P_\tau(\tau=\tau_0)$$

Different from the frequency hopping scenario, the symbol f_{out} is not counted in the time and frequency hopping mode, so according to the result of our previous research, the total collision bit number is $(m-b)y+bx$ and here $b=\tau-m\cdot\left\lfloor\frac{\tau}{m}\right\rfloor$, x and y are the numbers of equal pairs of the groups respectively.

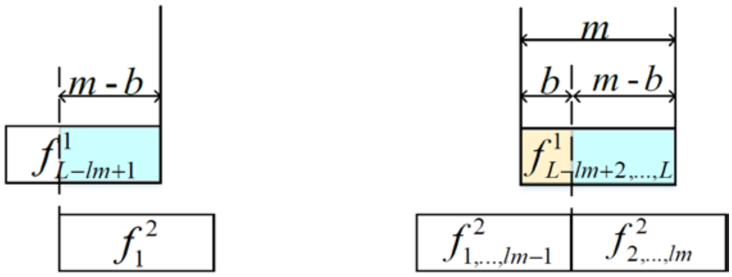


Figure 7. Collision model

Considering the error and erasure correction ability of the decoder α, the probability of non-collision could be represented as follow,

$$P_{nc\tau}=\sum_{x_0=0}^{\min(ML-1-\left\lfloor\frac{\tau_0}{m}\right\rfloor,\left\lfloor\frac{\alpha mML}{b}\right\rfloor)}\ \sum_{y_0=0}^{\min(ML-\left\lfloor\frac{\tau_0}{m}\right\rfloor,\left\lfloor\frac{\alpha mML-bx_0}{m-b}\right\rfloor)}P(x=x_0)\cdot P(y=y_0)$$

$$l_m=ML-m\cdot\left\lfloor\frac{\tau}{m}\right\rfloor$$

Here x and y obey the binomial distribution and their expression is shown as follow,

$$P(y=y_0)=C_{l_m}^{y_0}\left(\frac{1}{M^2N}\right)^{y_0}\left(1-\frac{1}{M^2N}\right)^{l_m-y_0}$$

$$P(x=x_0)=C_{l_m-1}^{x_0}\left(\frac{1}{M^2N}\right)^{x_0}\left(1-\frac{1}{M^2N}\right)^{l_m-1-x_0}$$

For the network scenario, with the number of user of U, the collision probability satisfy the following expression.

$$P_c=\sum_{u=1}^{U}p_{nc}p_u(u)$$

Assuming the total number of packet U in the network satisfy the classical Poisson distribution with parameter of T as follow. Here the bigger of parameter T means the busier of the network.

$$p_u(u)=\frac{T^u e^{-T}}{u!}$$

2.4 The algorithm of time and frequency hopping sequence

Classical M sequences with good correlation property are widely used in communication areas, such CDMA system. As, these sequences can be easily constructed by linear feedback shift registers (LFSR) [10], there are different sequence at most for the LFSR with length of n. So we can make use of the particularity of m sequences to generate TH and FH sequences as described in [11].

3. Simulation Results

To prove the effectiveness of time and frequency hopping system compared with frequency hopping system, a scenario was simulated with different the error and erasure correction coefficient α and the different number of user. The total size of transmit data is 30960 with 12 frequency slot and the number of time slot in TH-FH model is set as follow.

$M = U$

The simulation result of correct probability for data transmitting is given in the Fig. 8 with different error and erasure correction coefficient.

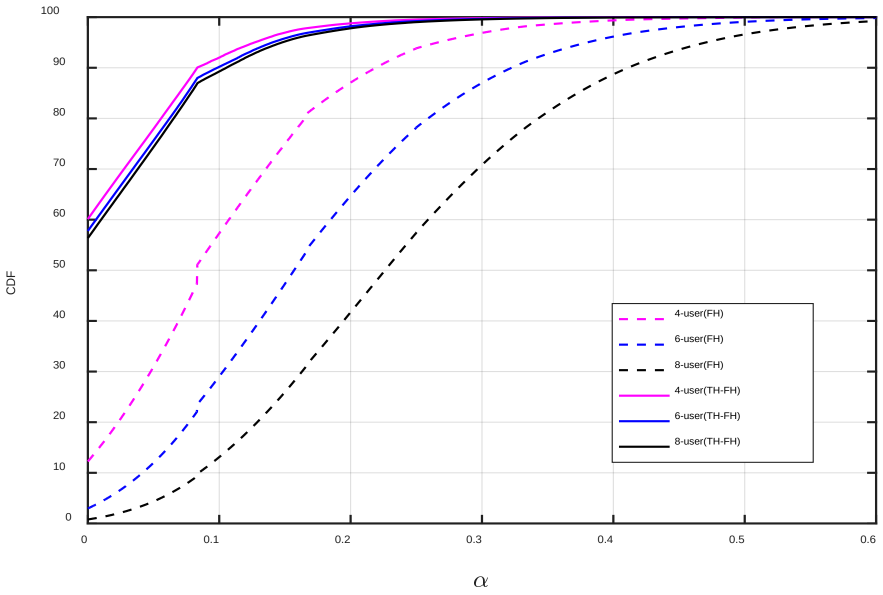


Figure 8. correct transmit probability for different α and number of user

From the above result, compared with the continental frequency hopping problem, the collision probability of TH and FH model is much lower, inversely with number of time hopping. That mean with sparser of time slot, the total collision probability of tow user will be decreased with the same size of data.

4. System Design and Its Implementation

4.1 System design

Here a time and frequency hopping system is designed with sixteen frequency slot of 50MHz bandwidth, and the max stray level is required well than 45dBc, the switch time of hopping frequency time is than 300 ns.

DDS and PLLs are two classical frequency source generation techniques. PLLs framework can generate radio waves that generate very high frequency with wide bandwidth and better frequency spectrum purity. However, due to the closed-loop structure, the frequency lock speed cannot satisfy the requirement. Another framework, compared with PLLs, DDS shares the advantage of high frequency resolution, short frequency conversion time. While it also has the disadvantages such as output stray suppression and limited working frequency.

To satisfy the system requirement we present the following scheme: the hopping time intermediate frequency signal and hopping frequency radio signal is generated independently with separate digital analog converter as show in Fig. 9. Time hopping and frequency hopping are tuned by hopping time pattern and hopping frequency pattern generated separately in FPGA. Specifically to maintain the initial phase equalization and satisfy the hopping frequency switching time, overall samples frequency of digital analog converter are generated by doubling frequency signal of 100MHz oscillator. In order to suppress the stray level of DDS and reduce the number of cavity filter, the initial local frequency generated by digital converter 2 is more than 2GHz and convert to 9.1GHz ~9.9GHz by doubling frequency device, here the third sampling interval of digital analog converter 2 are employed. For the time hopping signal, the second sampling interval is firstly used and then use frequency multiplier to transfer the frequency to 1.5GHz to alleviate the burden of band filter after the mixer.

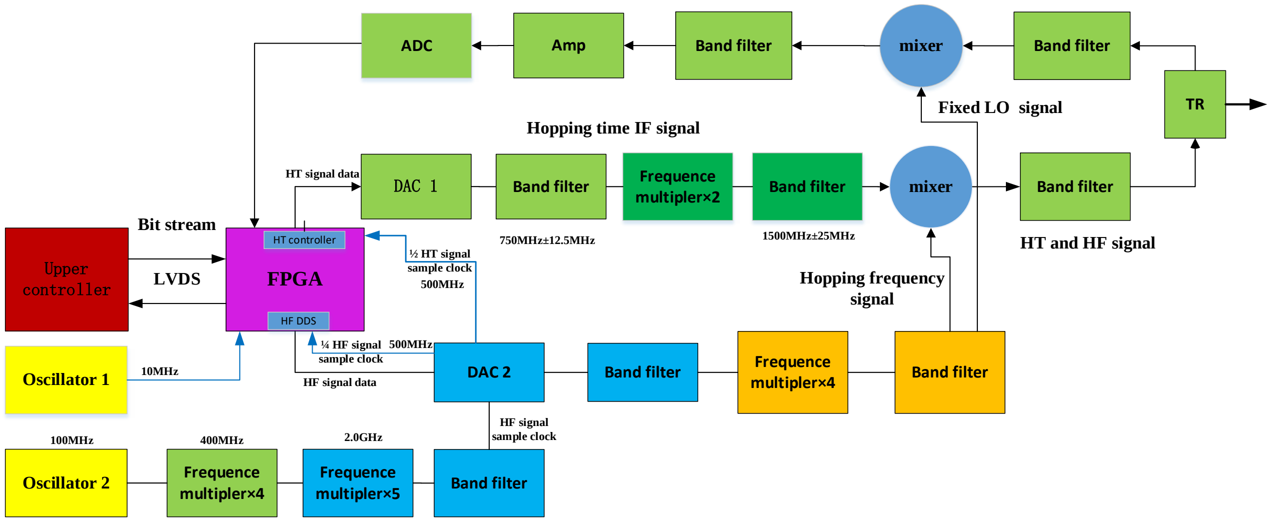


Figure 9. framework of TH and FH system

4.2 Implementation and measurement

Based on above system diagram, the TH and FH system was designed and manufactured. The following picture as shown in Fig. 10 are the front and back side of the TH and FH system. The hopping time with four different users was realized with FPGA and the result is shown in the Fig. 11.

(a) Front side (b) Back side

Figure 10. TH and FH hopping system

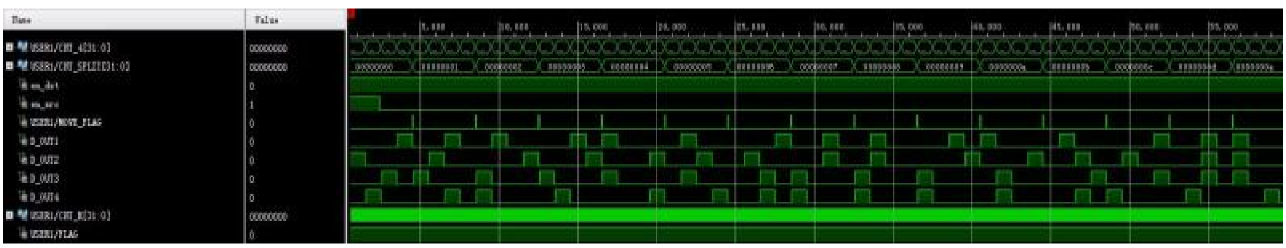
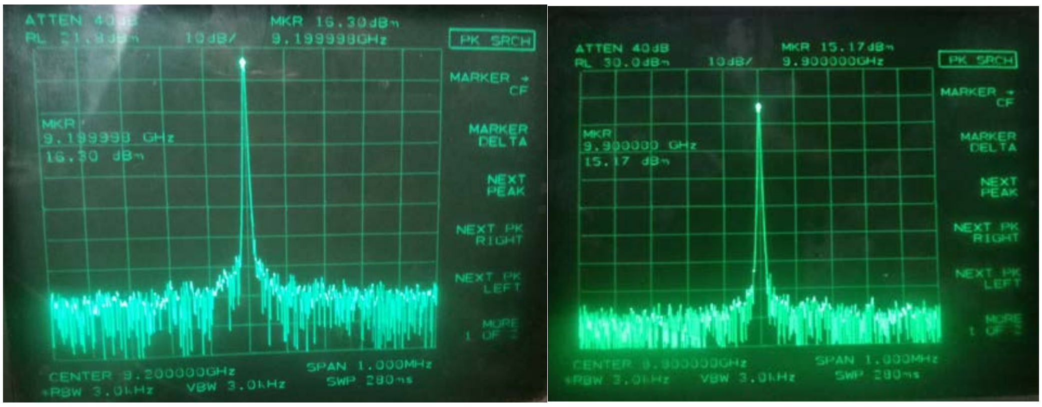


Figure 11. Time hopping result for different users

We test eleven frequency hopping points as shown the following table and omitting the last decimal, a table of power and spurious is formed, shown in the Table 1 and the Fig. 12 frequency hopping measurement result

Table 1. Measurement of power and spurious for frequency hoping

Output	Frequency (GHz)								
	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
Power (dBm)	15.2	16.3	16.0	15.5	15.8	16.2	15.9	15.5	15.2
Spur (-dBc)	46	51	45	49	47	48	49	50	46
Phase noise (dBc/1kHz)	-101	-103	-103	-102	-102	-104	-103	-102	-102



(a) 9.20GHz (b) 9.90GHz

Figure 12. frequency hopping measurement result

5. Conclusion

In this paper, the TH and FH access model was analyzed. Compared with frequency hopping model, by theoretical analysis and simulation validation, we prove the time and frequency hopping is meaningful to engineering. Furthermore, a TH-FH system with more than 800MHz was designed and manufactured based on the above model, the simulation results and measurement shows the effectiveness of TH-FH model.

References

[1] Simon M K, Levitt B K, Omura J K, et al. Spread spectrum communications. Volume 1, 2 & 3 [J]. NASA Sti/recon Technical Report A, 1985, 87.

[2] Pursley M B, Skinner J S. Adaptive coding for frequency-hop transmission in mobile ad hoc networks with partial-band interference [J]. IEEE Transactions on Communications, 2009, 57 (3): 801 - 811.

[3] Tomas E T, “Time-hopping sequence constructions for impulse radio,” IEEE International Conference on Communications, 28 April- 2 May, 2002.

[4] Niu, X., D. Peng and Z. Zhou, “Frequency/time-hopping sequence sets with optimal partial Hamming correlation properties,” Science China Information Sciences, 2012. 55 (10), pp. 2207 - 2215.

[5] Li Z, Chang Y, Jin L, et al. Analysis of FHMA performance on block cipher based frequency-hopping sequences [J]. IEEE Communications Letters, 2004, 8 (7): 434 - 436.

[6] Guan L, Li Z, Si J, et al. Analysis of asynchronous frequency hopping multiple-access network performance based on the frequency hopping sequences [J]. Communications Iet, 2014, 9 (1): 117 - 121.

[7] Xi Yan, Dehun Guo, Zhibo Zhang.The Performance Analysis of Asynchronous FHMA Network Based on the Cognitive Frequency Hopping Sequences. International Conference on Communication Software and Networks [C], p 50-3, 2018

[8] Zhang Zheng-ming WANG Jin, Research of chaotic FH sequences generated by combined map [J]. Chinese Journal of Radio Science, 2006, 21 (6): 895 - 898.

[9] Z. H. Guo, Y.G. Chen, Q. Li, C.B. Yin, T.H. Zhang, "Improvement of frequency hopping sequences based on Logistic map", Systems Engineering and Electronics, Vol.31, No.4, pp.773 – 776, 2009.

[10] LEMPEL ABRAHAM, HAIM GREENBERGER, "Families of Sequences with Optimal Hamming Correlation Properties," IEEE Transactions on Information Theory, 1974. 20 (1), pp. 90 - 94.

[11] Xiao Yang, Jinrong Liu, Tao Dong, Yinchuan Liang, Jianming Zhou, and Yu Wang, "Design of Frequency Time Hopping System Used in Airborne Data Link," IEEE International Conference on Communications Technology,2015, pp:817 - 820.