Comparing performance of FH and AFH systems

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Summary
The aim of this article is to compare the performance of AFH with the FH technique, using a mathematical model. The performance criterion for comparing the systems is the probability of collision between the communication system and the static or dynamic jammer in the communication band. The proposed model allows assessing the benefit of the AFH technique compared with FH. Using the model, it is possible to optimize AFH systems for the supposed number and type of jammers.

Key words:
Frequency Hopping, Adaptive Frequency Hopping, static jammer, dynamic jammer.

1. Introduction

The technique of Frequency Hopping (FH) belongs to the group of modulations with spread spectrum. The frequency hopping technique is, in principle, a narrow-band transmission at a given moment of time but over a longer period of time it will be spread over the allocated spectrum due to the changes in carrier frequencies. The principle of this technique consists in rapid frequency switching of carrier frequency in a pseudo-random sequence, which is known to both the receiver and the transmitter.

The technique of Adaptive Frequency Hopping (AFH) is based on the FH technique complemented with the ability to recognize static jammed frequencies and then avoid these frequencies. The parameters used in practice for the detection of static jammed frequencies are, for example, signal strength value on individual channels using the RSSI (Received Signal Strength Indication), the PLR (Packet Loss Ratio) or the BER (Bit Error Ratio). After the evaluation of the measurement, the AFH equipment sorts the frequency channels into the good and the bad ones. Non-jammed channels are identified as good channels while jammed channels are identified as bad channels. In the pseudo-random sequence for channel switching, the bad channels are replaced by good channels [1].

The advantages of systems with the frequency-hopping technique are, in particular, increased resistance to interference and security. Both advantages follow from the principle of the frequency hopping technique.

The aim of this article is to compare the performance of AFH with the FH technique, using a mathematical model. The performance criterion for comparing the systems is the probability of collision between the communication system and the static or dynamic jammer in the communication band. We regard as a static jammer any radio device transmitting at a fixed frequency. As a dynamic jammer we regard any device with the FH or AFH technique, which has the same parameters as the system under consideration.

2. Current status

Models are currently described that deal with the coexistence of the Bluetooth system with adaptive frequency hopping and with system 802.11b with direct spread spectrum [2], [3]. Alternatively, a model comparing the coexistence of two different techniques, AFH and system 802.11b, is described in [4]. Furthermore, a model that deals with the time necessary to detect a bad channel and exclude it from usage in the AFH system is described in [3]. However, none of these models deals with the behaviour of multiple frequency hopping systems with the same parameters in the band where static jammers work.

3. Model

The mathematical model models the probability of collision between the FH or AFH communications system and the static or dynamic jammer in the communication band. For simplicity, it is assumed that the bandwidth of the jammer is the same as the bandwidth of one channel of the FH or AFH system.

The probability of a collision or a jump of the FH system to the jammed channel is given by formula (1), where N is the number of communication channels, R is the number of channels jammed by static jammers, and S is the number of channels jammed by dynamic jammers (i.e. number of another FH networks):

$$P_{FH} = 1 - \left(\frac{N-R}{N} \right) . \left(\frac{N-1}{N} \right)^{S} \qquad (1)$$

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The first factor represents the probability that the FH station is tuned to a channel that is not jammed by static jammer. The second factor represents the probability that none of the S dynamic jammers transmits on a randomly selected channel, i.e. all S jammers are located in one of (N-1) remaining channels.

Multiplying the two previous factors, we get the probability of two independent phenomena (for static and dynamic jammers). We get the probability of the jump on a

non-jammed channel. To get the probability of a jump on a jammed channel, we have to subtract from 1 the calculated probability and we get the resulting probability P_{FH}.

In the mathematical model, we consider an idealization of the AFH system. We assume a correct delivery of the list with bad channels to individual stations. It is also assumed that, after a sufficiently long period of time, all statically jammed channels are detected. We neglect collisions caused by the search for statically jammed channels because of the time necessary for their detection and the total time of data transmission.

Due to the established simplifying assumptions, the results obtained will be the best that can be achieved. In practice, the AFH system can not be better. An important parameter of AFH is the parameter R_{MAX}, which indicates the maximum number of replaced channels. The number of replaced channels is usually limited due to potential desynchronization of stations, which could occur in the case of an unsuccessful handover of the list with bad channels to individual stations. Furthermore, we consider that all the dynamic jammers S have a parameter R_{MAX} identical with our system with AFH.

By analogy, the probability of a collision or jump of the AFH system on a jammed channel is given by formula (2), where R_{MAX} is the maximum number of channels replaced by the AFH system.

The calculation of the probability of collision for the AFH system is performed like that for FH. Due to the AFH system, it is possible to replace statically jammed channels by non-jammed channels and therefore the variables N and R are replaced by n and r. The variable n is the current number of communication channels used in the AFH system, where r static jammers are located. It results from the function principle of AFH system that the total number of communication channels N is reduced in dependence on the number of static jammers R, but maximally by about R_{MAX}, to the current number of communication channels n. That is why the AFH system is able to completely eliminate the effect of R, but not more than R_{MAX} static jammers. The number of static jammers exceeding R_{MAX} is denoted r and they stay in the frequency band with n channels.

The behaviour of variables n and r should be divided into two intervals. The first interval defines the behaviour of variables when the number of static jammers R is less than or equal to the limit R_{MAX}. The AFH system detects the static jammers, and the channels occupied by the jammers are no longer used. The total number of channels used will be decreased by the total number of static jammers R to $n = N\text{-}R$ channels. At the same time, in the band of n channels there are no longer any static jammers, and therefore $r = 0$.

The second interval defines the behaviour of variables when the number of static jammers R is higher than the limit R_{MAX}. In this interval, the AFH system eliminates the maximum number of replaced channels. This will reduce the total number of channels used to $n = N\text{-}R_{MAX}$ channels. At the same time, in a band of n channels there are no longer the original R jammers, but fewer by R_{MAX}, and therefore the number of jammers in a band of n channels is equal to $r = R\text{-}\ R_{MAX}$ jammers.

$$P_{AFH} = 1 - \left(\frac{n-r}{n}\right) . \left(\frac{n-1}{n}\right)^{S} \qquad (2)$$

$$n = \begin{cases} N - R, R \le R_{MAX} \\ N - R_{MAX}, R > R_{MAX} \end{cases} \qquad r = \begin{cases} 0, R \le R_{MAX} \\ R - R_{MAX}, R > R_{MAX} \end{cases}$$

A comparison of the two systems can be made using formula (3), where we subtract the collision probability of the FH system from that of the AFH system; the result will be related to the collision probability of the FH system, and we will get the resulting gain of AFH. A positive result shows the advantage of AFH and a negative result shows its disadvantage compared to the FH system.

$$A = \frac{P_{FH} - P_{AFH}}{P_{FH}} \qquad (3)$$

4. Results

The above analyses were calculated, for illustration, with specific parameters but the following conclusions can be considered general and valid also for different parameters.

The calculation of gain A, which is represented by the graph in figure 1, was performed according to formula (3). To illustrate the analysis, the following parameters were used for the calculation: N = 100, R_{MAX} = 20, R = 0 to 40 and S = 1 to 40. From figure 1, where A = f (R, S), we can see the following:

If only dynamic jammers (R = 0) are in the communication band, the calculated gain A is equal to zero. In this case, using the AFH system is totally unnecessary and in practice even inappropriate, due to the simplifying assumptions (we do not consider the necessary redundancy of AFH).

Compared to FH, the AFH system becomes advantageous if there are static jammers *R* in the band, and then it is true that $R > 0$. That advantage gradually decreases with increasing number of dynamic jammers *S* and also with increasing number of static jammers *R*, when $R > R_{MAX}$.

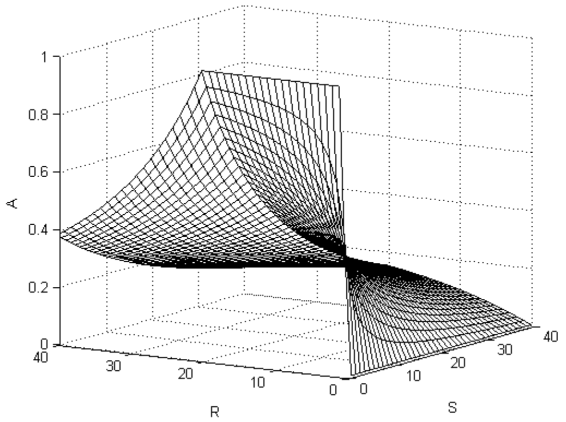

Fig. 1: Comparing the performance of AFH with FH in the band with static and dynamic jammers (N = 100, R_{MAX} = 20, R = 0 to 40 and S = 1 to 40).

Furthermore, an analysis of the gain was done in the area of dynamic jammers for a constant number of static jammers.

The calculation of the gain was made according to formula (3), which is represented by the graph in figure 2, where $A = f(S)$. To illustrate the analysis, the following parameters were used for the calculation: N = 100, R_{MAX} = 20, R = 10 and S = 1 to 100. In this case, the AFH system can achieve a better gain than FH in the band with dynamic jammers *S*. For example, when S = 10, the gain is A = 0.4. In the area where the number of dynamic jammers *S* is close to the number of channels *N*, the gain of AFH is zero or even negative.

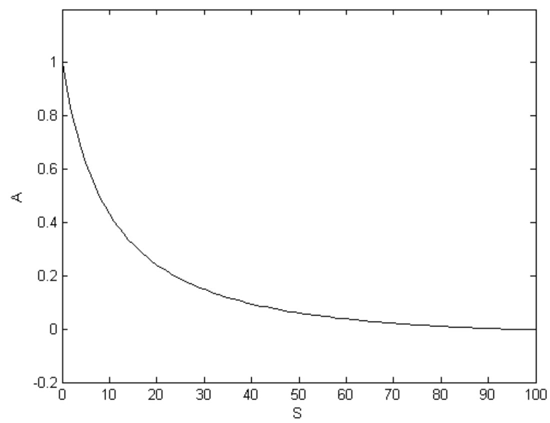

Fig. 2: Comparing the performance of AFH with FH in the band with dynamic jammers (N = 100, R_{MAX} = 20, R = 10 and S = 1 to 100).

In practice, the parameter R_{MAX} is very important, because it can be set. The number of channels, *N*, is usually fixed. The number of static or dynamic jammers (*R* or *S*, respectively) cannot be usually influenced.

The calculation of the gain was made according to formula (3), which is represented by the graph in figure 3, where $A = f(R)$. To illustrate the analysis, the following parameters were used for the calculation: N = 100, R = 0 to 10, S = 0, and R_{MAX} = 10, 20, 30, and 40.

We can see from figure 3 that with increasing R_{MAX} the steepness of curve *A* decreases. For example, if we choose the threshold gain A = 0.4 as sufficient, we find that for R_{MAX} = 10 the number of static jammers *R* can be as much as 21, which is 11 more than the limit of R_{MAX}. For R_{MAX} = 20 it is 18 more. For R_{MAX} = 30 it is about 21 more, and for R_{MAX} = 40 it is 22 more. Increasing the value of the parameter R_{MAX} has a disadvantage in that it brings the risk of desynchronized stations and narrowed frequency of the band.

Due to the given disadvantage and the steepness of curve *A*, the optimal R_{MAX} for N = 100 is a value between 20 and 30. Generally, the optimal value of R_{MAX} is between 20% and 30% of *N*.

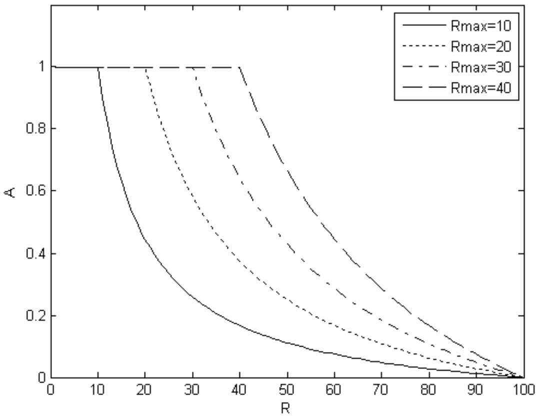

Fig. 3: Comparing the performance of AFH with FH in the band with static jammers for different R_{MAX} (N = 100, R = 0 to 10, S = 0 and R_{MAX} = 10, 20, 30, 40).

3. Conclusion

The proposed model allows assessing the benefit of the AFH technique over FH. The highest benefit of AFH compared with FH is in the band with static jammers, as expected.

Using the model, it is possible to optimize the parameter R_{MAX} of the AFH system for the supposed number and type of jammers. Increasing the value of the parameter R_{MAX} leads to increased resistance of AFH to higher numbers of static jammers. We have to bear in mind that increasing the value of this parameter can lead to the desynchronization of stations and also to the narrowing of the frequency band. A significantly narrowed frequency spectrum can lead to a simplification of the interception of the AFH system compared to the FH system. By increasing the total number of channels, *N*, it is possible to prevent any narrowing of the frequency band.

Based on the data obtained from the model, it is possible to choose the optimum error control coding for the supposed number and type of jammers.

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