# Differential Frequency Hopping Systems Using Soft Decision Viterbi Decoding Algorithm

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*Abstract* — **Differential frequency-hopping (DFH) technique has been widely studied and applied in the military communications due to its many desirable features, such as reliable high data rate transmission characteristics, anti-jamming abilities and information security. In order to improve the information security of the conventional DFH systems, a novel DFH system with the G-function controlled by the well-known maximal length sequences, is proposed in this paper. In addition, both BCH code and soft decision Viterbi algorithm are also used in the proposed scheme to further improve the system performance. Our results show that the proposed scheme not only provides the higher information security but also improves the system performance indeed, compared to the conventional schemes.**

## I. INTRODUCTION

Differential frequency-hopping (DFH) technique was proposed by American Sanders Company to provide higher data rate (up to 19.2 Kbps) at the hopping rate of 5000hps in high-frequency (HF) band [1], [2]. DFH technique has been widely studied and applied in the HF wireless communications and military communications due to its many desirable features, such as reliable high data rate transmission characteristics, anti-jamming abilities, multipath fading mitigation and information security [2], [3]. In DFH systems, the frequency transition function, so-called G-function, which determines how the transmitted frequency is depended on both the current data symbol and the previous transmitted frequency, is the key technique to improve the system performance and transmission data rate [2]-[5]. In addition to the system performance, the information security during the transmission of data is another important issue for the DFH systems, especially for the applications of the military communications. Recently, several design methods for G-function were successively proposed to improve both system performance and information security [2], [3], [6]-[10].

The organization of the rest of this paper is as follows. A novel DFH system with the G-function controlled by the well-known maximal length sequences and with the use of both BCH code and soft decision Viterbi algorithm, is proposed in Section II. In order to validate the security ability of the proposed scheme, continuity estimation test is studied in Section III. In addition to the issue of the security ability, the performance of the proposed DFH system under the additive white Gaussian noise (AWGN) channel and Rayleigh fading channel, respectively, is also provided to identify the feasibility and validity of the proposed scheme in this section. The simulation results show that not only 2D continuity property of the proposed scheme can be effectively improved by utilizing the maximum length sequences, but also the system performance will further get better due to the use of BCH code and soft decision Viterbi algorithm indeed.

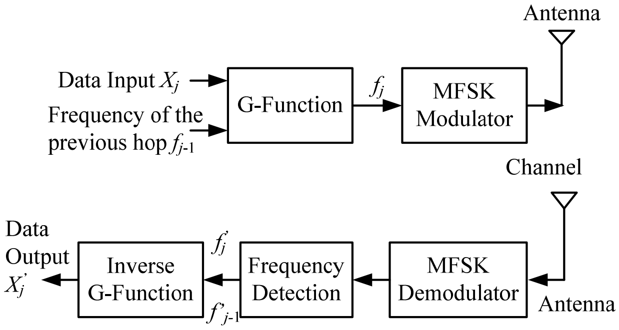


**Fig. 1 System model of the conventional DFH system**

## II. SYSTEM MODEL

The main difference between the concept of DFH system and the conventional frequency-hopping (FH) system is that carrier frequencies of the successive hops used for the former are controlled by both transmitted data symbols and frequency transition function, but those used for the latter are controlled by FH patterns [2], [4]. In this section, the system models of the conventional DFH scheme and proposed novel DFH scheme are briefly introduced, respectively, as follows.

### A. Conventional DFH Scheme

Fig. 1 shows the system model of the conventional DFH system. In the conventional DFH system, the current transmitted frequency $f_j$ is mainly depended on both of the current data symbol $X_j$ and the previous transmitted frequency $f_{j-1}$, according to the following equation [2]-[5]:

$$f_j = G(f_{j-1}, X_j), \tag{1}$$

where $G$ is the frequency transition function (FTF), so-called G-function, which is the key technique for DFH systems, $f_j \in \{F_0, F_1, F_2, \cdots, F_{M-1}\}$, $M$ is the number of available frequencies in DFH systems, and each hop contains *bph* data bits information.

### B. Novel DFH Scheme

As shown in Fig. 2, a novel DFH system with the G-function controlled by the well-known maximal length sequences $S_m$ and with the use of both BCH code and soft decision Viterbi algorithm is proposed, so-called State-Trellis

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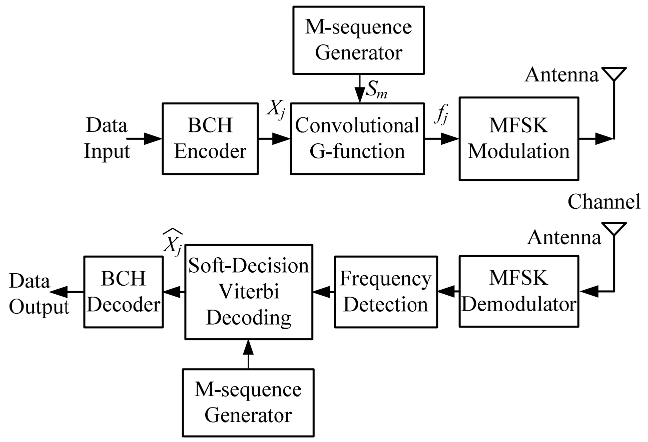


**Fig. 2 System model of the proposed DFH system**

Soft-Decision (ST-SD) scheme in this paper. In the proposed ST-SD scheme, the convolutional G-function is mainly generated with the use of convolution code and controlled by the maximal length sequences to improve the information security of the conventional DFH system [6]-[8]. Moreover, the proposed ST-SD scheme also utilizes the BCH code [11] and soft decision Viterbi algorithm [9], [10] in the transmitter and receiver, respectively, to further improve the system performance.

Compared to the G function design for the conventional DFH system in (1), the current transmitted frequency $f_j$ of the proposed ST-SD scheme is not only depended on both of the current data symbol $X_j$ and the previous transmitted frequency $f_{j-1}$, but also depended on the other previous $k$-1 transmitted frequencies $f_{j-2}$, $f_{j-3}$,…, $f_{j-k}$ [7] and maximal length sequences $S_m$ based on the following equation:

$$f_j = G(f_{j-1}, f_{j-2}, \cdots, f_{j-k}, X_j, S_m) \tag{2}$$

Shown in Fig. 3 is the block diagram of the proposed convolutional G-function generated with the use of convolution code and controlled by maximal length sequences $S_m$ [6], and the generator polynomial of the sequences $S_m$ used for all numerical examples in Section III is given by $p(X)= X^{10}+X^3+1$ [12]. This figure illustrates how to generate the current state $V_j$ in the Trellis diagram and the current transmitted frequency $f_j$ by utilizing the proposed convolutional G-function. The current state $V_j$ and the current transmitted frequency $f_j$ are given by

$$\begin{aligned} V_j = {} & D_0 \times 2^{m_2-1} + D_1 \times 2^{m_2-2} + \cdots + D_{bph-1} \times 2^{m_2-bph-2} \\ & + B_0 \times 2^{m_2-bph-3} + B_1 \times 2^{m_2-bph-4} + \cdots + B_{m_2-2} \times 2^0 \end{aligned} \tag{3}$$

and

$$\begin{aligned} f_j = {} & Z_1 \times 2^{m_3-1} + Z_2 \times 2^{m_3-2} + \cdots + Z_x \times 2^{m_3-x} \\ & + C_0 \times 2^{m_3-x-1} + C_1 \times 2^{m_3-x-2} + \cdots + C_{m_3-x-1} \times 2^0 \end{aligned} \tag{4}$$

where the system parameters $m_2, m_3, g$ and $x$ are given by

$$m_2 = \log_2 V, \; m_3 = \log_2 M \tag{5}$$

and

$$g = 2^x, x = 1,2,...,\log_2 M - bph - 1 \tag{6}$$

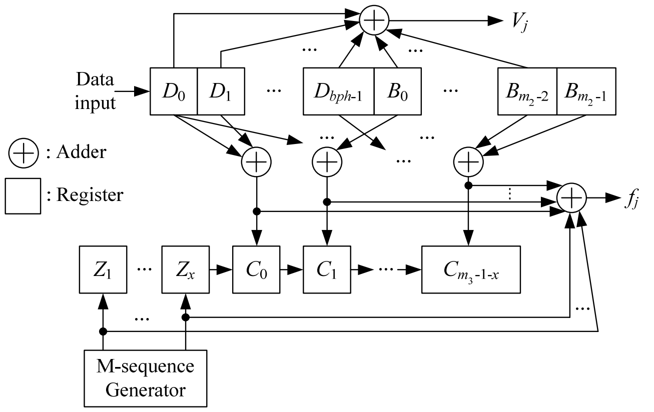


**Fig. 3 Block diagram of the proposed convolutional G-function generated with the use of convolution code and controlled by maximal length sequences**

where $V$ denotes the number of states in the Trellis diagram and $V \geq 2$ and the initial state $V_0$=0 (i.e., $j$=0 case), $M$ is the number of available carrier frequencies and $M \geq 4$, $g$ is the number of groups controlled by maximal length sequences $S_m$, $x$ is the number of registers used for the group determination and $bph$ denotes the number of transmission data bits per hop.

## III. NUMERICAL RESULTS

The continuity estimation test is commonly used to validate the security ability of the DFH system [2]-[4]. In this section, the security abilities of both proposed ST-SD scheme and the conventional DFH scheme are firstly compared and validated through the test results. Moreover, in order to identify the feasibility and validity of the proposed scheme, the simulation results of system performance of both schemes under AWGN channel and Rayleigh fading channel are also provided and compared as follows.

### *A. $\mathbf{x}^2$ test for the 2D continuity*

The $\mathbf{x}^2$ test for the 2D (two-dimensional) continuity of the DFH system is given by [2]-[4]

$$\mathbf{x}^2(M^2-1) = \sum_{i,j=0}^{M-1} \frac{(N_{ij} - L/M^2)^2}{(L/M^2)} \tag{7}$$

where $N_{ij}$ denotes the number of appearance of frequency pairs ($F_i$, $F_j$), $M$ is the number of available carrier frequencies and $L$ is the frame length. The scheme will satisfy the definition of 2D continuity property once the result of the scheme (based on (7)) is less than $\mathbf{x}^2_{0.05}(M^2-1)$ which is the theoretical value at the 5% significance level.

Fig. 4 compares $\mathbf{x}^2$ test results of 2D continuity of the conventional DFH scheme and the proposed ST-SD scheme with various $g$={1, 2, 4}, where $M$=32, $V$=32, and $bph$=2. The simulation results show that the 2D continuity property of the former is always worse than that of the latter, and only the proposed ST-SD scheme with $g$={2, 4} can satisfy with the 2D continuity criteria (i.e., $\mathbf{x}^2_{0.05}(M^2-1) = 1098.3$ for $M$=32 case). It is because that partitioning all available

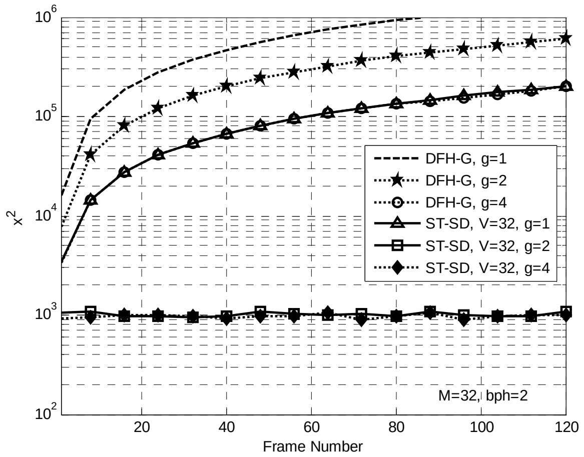


**Fig. 4** $x^2$ **test results for 2D continuity of the conventional DFH scheme and the proposed ST-SD scheme with various** $g$**={1,2,4}, where** $M$**=32,** $V$**=32, and** $bph$**=2.**

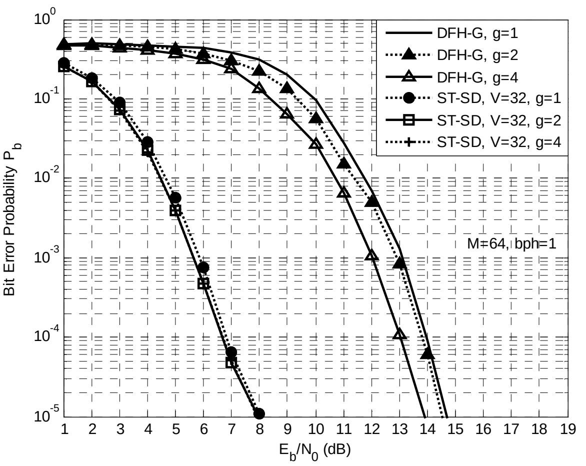


**Fig. 5 Bit error probabilities versus signal-to-noise ratio (*SNR*)** $E_b/N_0$ **for the conventional DFH scheme and the proposed ST-SD scheme with various** $g$**={1,2,4}, under the AWGN channel, where** $M$**=64,** $V$**=32, and** $bph$**=1.**

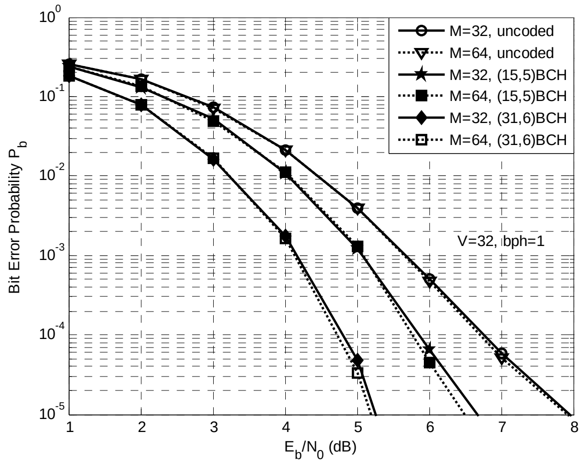


**Fig. 6 Bit error probabilities versus signal-to-noise ratio (*SNR*)** $E_b/N_0$ **for the proposed ST-SD scheme with various** $M$**={32, 64}, with and without the use of BCH code, under the AWGN channel, where** $V$**=32, and** $bph$**=1.**

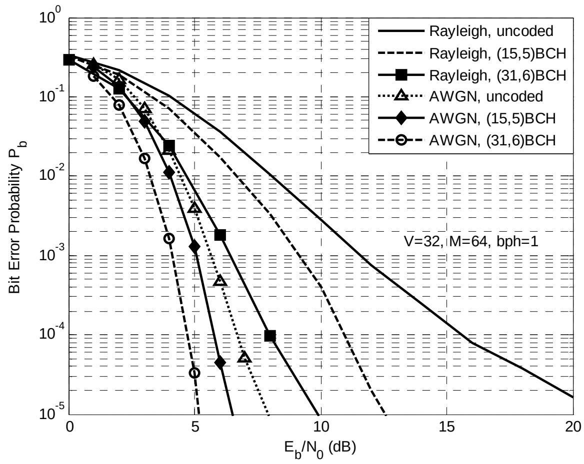


**Fig. 7 Bit error probabilities versus signal-to-noise ratio (*SNR*)** $E_b/N_0$ **for the proposed ST-SD scheme with and without the use of BCH code, under the AWGN channel and Rayleigh fading channel, where** $M$**=64,** $V$**=32, and** $bph$**=1.**

$M$ frequencies into $g$ groups and determining which group in use by the maximal length sequences will make all possible frequency pairs of the proposed ST-SD scheme approach the uniform distribution, such that the proposed scheme has the better 2D continuity property to improve the information security of the DFH system.

### *B. System Performance*

Shown in Fig. 5 are the bit error probabilities of the conventional DFH scheme and the proposed ST-SD scheme with various $g=\{1,2,4\}$ versus the signal-to-noise ratio (*SNR*) $E_b/N_0$, under the AWGN channel, where $M$=64, $V$=32, and $bph$=1. As expected, the bit error probability of each scheme improves as the value of $E_b/N_0$ increases. The bit error probability of the proposed ST-SD scheme is much better than that of the conventional scheme, due to the use of soft decision Viterbi algorithm in the receiver for the former scheme, as expected. For example, from Fig. 5 with $P_b \approx 10^{-4}$, we will get about 7dB improvement in the system performance of the proposed ST-SD scheme, compared with the conventional DFH scheme with $g$=1 case. However, unlike the conventional DFH scheme, the bit error probability of the proposed ST-SD scheme gets worse as the number of groups $g$ increases. In other words, the proposed ST-SD scheme provides a trade-off between the system performance and the number of groups for meeting the different system requirements, such as throughput and information security.

Fig. 6 shows bit error probabilities versus signal-to-noise ratio (*SNR*) $E_b/N_0$ for the proposed ST-SD scheme with various $M=\{32,64\}$, with and without the use of BCH code, under the AWGN channel, where $V$=32, and $bph$=1. As expected, the performance of the proposed scheme with the use of BCH code is always better than that of the proposed scheme without the use of BCH code, since the former uses error-correct coding technique to improve system performance, but also increases the system complexity. For example, from Fig. 6 with $P_b \approx 10^{-4}$, the proposed scheme with the use of (15, 5) BCH code and (31, 6) BCH code [11] under the same system parameters $M$=32, $V$=32 and $bph$=1 will obtain about 1dB and 2dB performance improvement, respectively, compared with the uncoded case.

In Fig. 7, the bit error probabilities of the proposed ST-SD scheme with and without the use of BCH code are plotted against the signal-to-noise ratio ($SNR$) $E_b/N_0$ under the AWGN channel and Rayleigh fading channel, respectively, where $M$=64, $V$=32, and $bph$=1. The performance improvement between the scheme with and without the use of BCH code in Rayleigh fading channel is larger than that in AWGN channel. For instance, from Fig. 7 with $P_b \approx 10^{-4}$, the proposed scheme with the use of (15,5) BCH code under Rayleigh fading channel will obtain about 5dB performance improvement, but under AWGN channel only about 1dB. In other words, the numerical results show that the proposed scheme can obtain the significant performance improvement by using error-correct coding technique indeed, especially in Rayleigh fading channel.

## IV. CONCLUSION

A novel DFH system with the G-function controlled by the maximal length sequences and with the use of both BCH code and soft decision Viterbi algorithm was proposed in this paper. The numerical results showed that the proposed ST-SD scheme not only provided the higher information security, but also improved the system performance indeed, compared to the conventional DFH scheme. Moreover, the results also showed that there was a trade-off between the bit error probability and the number of groups. If the system security was more important, one should choose the larger value of $g$ to obtain the higher information security. Otherwise, the proposed scheme with $g$=1 case (i.e., the scheme without partitioning available $M$ frequencies) provided the better performance, but lower information security.

## V. ACKNOWLEDGMENT

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