Epoch Time Estimation of the Frequency Hopping Signal

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Abstract

The paper investigates the epoch time parameters estimation of the frequency hopping FH signals, which are of major interest in most of the recent commercial applications. Two types of estimation models has been simulated and examined in this work. The first is the single-hop autocorrelation (SHAC) processor. It is considered as a means of estimating the epoch time of the FH signal in the presence of AWGN. The second is the expanded multiple stages-frequency hopping-hop rate detector (EMS-FH-HRD). The later has been modified in this work from the hopping rate detector, which detects only the presence of the FH signal, and operated in noisy environment. These two were independent of the hopping frequency pattern and the carrier phase (the sequence of the hopping frequencies is totally unknown.

These models have been simulated using Matlab version 6.5 and examined in AWGN environment. The results show that both SHAC and EMS-FH-HRD give acceptable results. The percentage of error increases as the SNR decreases. Furthermore, the EMS-FH-HRD gives better results than that of the SHAC and have no ambiguity as that SHAC at certain conditions. The advantage of EMS-FH-HRD epoch time estimator over SHAC is that it could estimate the normalized epoch time with very low percentage error and at even more condition where the SHAC fails.

Keywords: *Frequency hopping (FH), single-hop autocorrelation, Frequency hopping -hop rate detector, multiple stages-frequency hopping-hop rate detector, epoch time.*

1. Introduction

Spread spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information. The spreading in band is accomplished by means of a code which is independent of the data and synchronized with the code at the receiver which is used for dispreading and subsequent data recovery.

There are many types of spread spectrum; direct sequence (DS), frequency hopping (FH), time hopping (TH), chirp (pulsed FM) system and hybrid technique which is a combination of two spread spectrum techniques such as (DS/FH), (TH/FH) and (DS/TH) [1,2].

Frequency hopping (FH) is one of the important spread spectrum techniques, where the frequency of the baseband changed transmission signal is in a pseudo random manner over the required bandwidth. The hoping rate, f_h, and timing information are very important parameters in FH because they can be used as information for the interceptions activities, signal jamming, for the initial synchronization phase of friendly transmission and signal deciphering [3].

When the receiver and the transmitter are not synchronized, then, there is a timing offset between the first hop of the frequency hopping signal and the clock of the receiver. This is called the epoch time as shown in Fig (1). Epoch time = αT_h, where $0 < \alpha < 1$, and $T_h = 1/f_h$. [4]

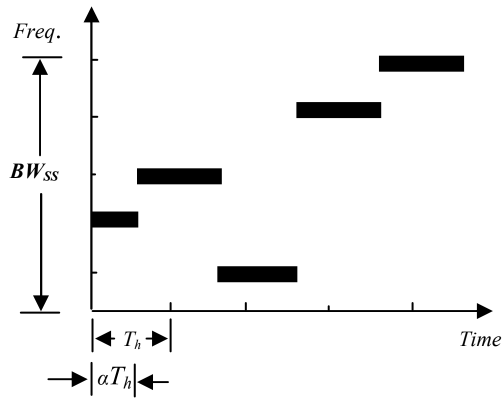

Fig. (1) Time-frequency characteristic of FH signal illustrates the epoch time αT_h

2. Estimation Theory and Application for FH signal

Estimation theory can be regarded as being concerned with the study of the desirable properties that an estimator should possess and of the logical consequences of assumptions that seem reasonable. One general approach to the estimation of moments like the mean, variance, etc.. of a random sequence is based on the intuitive connection between the mean value and the average of a large number of independent observations of a random variable. If $x_1, x_2, \ldots$ are statistically independent, that is, x_n is a purely random sequence, their common mean value can be estimated by the average of N observation values [5]

$$E[x_n] \approx \frac{1}{N}\sum_{k=1}^{N} x_k = \hat{\eta}_x \qquad \ldots\ldots\ldots\ldots \quad (1)$$

where $E[x]$ is the expected value of (x),

N is the number of observation,

and $\hat{\eta}_x$ is the estimated mean value.

(A hat will often be used to designate a variable which is an estimate.)

The N sample average has been proposed in Equ. (1) as an estimate of the mean value, and is said to be unbiased (good on the average) if :

$$E[\hat{\eta}_x] = \eta_x \qquad \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots \quad (2)$$

Another good property, that the estımate improves as more data become available is demonstrated by showing that the mean squared estimation error decreases according to the relation :

$$\lim_{N\to\infty} E\left[(\hat{\eta}_x - \eta_x)^2\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

An estimate with this property is said to be consistent. The mean squared error between a consistent estimate and its mean goes to zero for large N [5]. In this work the main parameter of the frequency hopping signal was estimated, epoch time. In the initial synchronization phase of a friendly transmission, estimating this parameter is a prerequisite for the demodulation procedure.

3. Epoch Time Estimation Based on (SHAC) Processor

A block diagram of the (SHAC) processor is the same as multiple hop autocorrelation (MHAC) as shown in Fig (2). When the signal's hop rate is known a priori (i.e., in a friendly transmission, or estimated by MHAC), it is possible to perform an epoch estimation based on the power samples in the (SHAC) domain [6,7].

Here, the processor receives the signal hop by hop. Clearly, the unknown timing offsets (epoch) for successive hop observation cells are the same. Therefore, it is sufficient to analyze the operation and properties for the first interval $(0, T_h)$. The (SHAC) processor has the same structure as that of (MHAC) processor, except that of the autocorrelation waveform is defined over a single-hop time interval. After the autocorrelation process, the (SHAC) power sample is taken at a rate of B samples/sec., yielding $G_h = T_h.B$ samples over the interval $(0,T_h)$ [6,7]. The k^{th} power sample at $\tau_k = k/B$ can be expressed as :

$$W_{k,SH} = y^2_{SH}(\tau_k)\big|_{LPF} \qquad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

where $y^2_{SH}(t)\big|_{LPF}$ denotes the lowpass version of $y^2_{SH}(t)$. The power sampling in the (SHAC) domain suppresses the dependence on the actual hopping pattern, the candidate carrier frequencies, and the carrier phase, while maintaining the timing (epoch) information. The single hop weighted power sum is formulated as:

$$Y_{SH} = \sum_{k=1}^{\lambda G_h} \frac{W_{k,SH}}{(T_h - \tau_k)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Again, for large λG_h, λ less than or equal 0.1, and a fixed α the statistic Y_{SH} is approximately Gaussian distributed with a fixed mean and variance [6]. At the receiver, the hop rate and the signal power are known. If the new statistic function is defined as [8] :

$$Z_{SH} = (1/4) + ((Y_{SH} - P(\lambda,G_h,S) - q(\lambda,G_h,N_o,B))/a(\lambda,G_h,S)) \ldots (6)$$

where

$$P(\lambda,G_h,S) = S^2 G_h\{2\lambda + 2\ln(1-\lambda) + \lambda/(1-\lambda)\} \quad \ldots\ldots\ldots (7)$$

$$a(\lambda,G_h,S) = 2S^2 G_h\ \lambda/(1-\lambda) \quad \ldots\ldots\ (8)$$

For λ less than or equal 0.1 and for $\lambda G_h >> 1$, since Y_{SH} is approximately Gaussian distributed, so is Z_{SH}. For a given value $Z_{SH} = z$, the Maximum Likelihood ML estimator $\hat{\alpha}_{ML}$ minimizes $(z-\mu(\alpha))^2$ (the exponent of the Gaussian distributed of Z_{SH}), subject to the constraint $0 < \hat{\alpha}_{ML} < 1$. In other word, $\mu(\hat{\alpha}_{ML}) = z$, where $\mu(\alpha)$ is the mean value of α, if this has a solution in (0,1), otherwise $\hat{\alpha}_{ML} = 0$ or 1, depending on the sign of $(z-\mu(\alpha))$. Since $\mu(\alpha)$ is symmetric with respect to α =0.5, the estimator based on the ML criterion possesses an (α, 1- α) estimation ambiguity, which means that the normalized epoch values α and 1- α can not be distinguished by the estimator. For this reason, α has been taken less than or equal 0.5 [8].

4. Epoch Time Estimation Based on (EMS-FH-HRD) Processor

The block diagram of the expanded multiple stage frequency hopping hop rate detector modified in this work from the hopping rate detector [3] is as shown in Fig. (3). When the

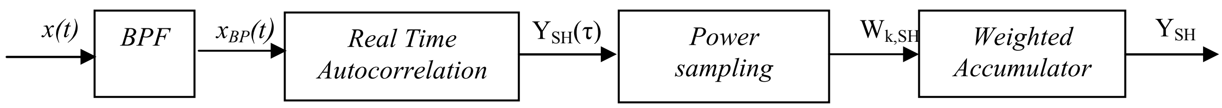

Fig (2) Autocorrelation Processor

signal output from the first multiplier, is applied to a narrowband bandpass filter and then processed by a phase estimator, it will produce the desired hop timing (epoch) estimation. The signal that enters to the phase estimator is sub divided in a multiple branches. The number of these branches depends on the accuracy of the estimator. Each branch contains a multiplier to multiply the input signal by a reference signal having the same frequency of the input signal, (the hop rate of the input signal was estimated earlier in the first stage of the MS-FH-HRD), but there are a phase differences between the signals in each branch. An integration operation carrying out individually to give an appropriate value.

All the values output from the integrals are compared to select the maximum one, where this value will correspond to the estimated value of epoch time ($\hat{\alpha}$).

5. Computer Simulation for the Epoch Time Estimation Based on SHAC

The simulation model for this estimator is shown in Fig (4), except that the autocorrelation is defined over a single hop time interval T_h, and G is replaced to G_h = ($B.T_h$). The SHAC processes the received signal hop by hop. The unknown timing offsets for successive hop observation cells are the same. Therefore, it is sufficient to analyze the operation of the first interval ($0,T_h$). For this estimation test, the hop rate =100 hop/sec. (T_h= 0.01 sec.) and λ=0.1 . Different values of SNR (-10,-5, 0, 5, 10) dB, and the epoch time values from 0.1 to 0.5 in step of (0.1), are used in the evaluation. Fig (5) shows the exact epoch time and the error percentage for different SNR.

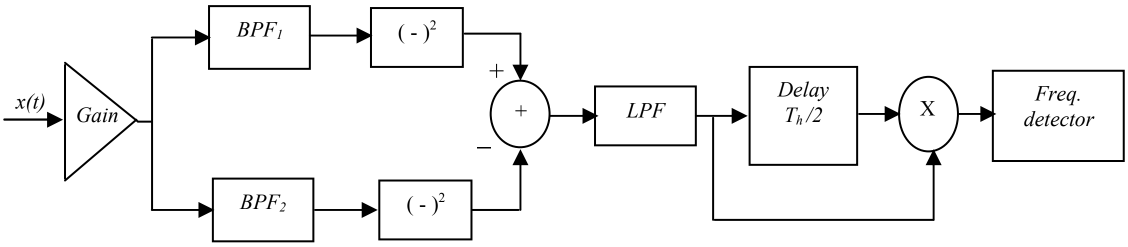

Fig (3a) Frequency Hopping- Hop Rate Detector FH-HRD

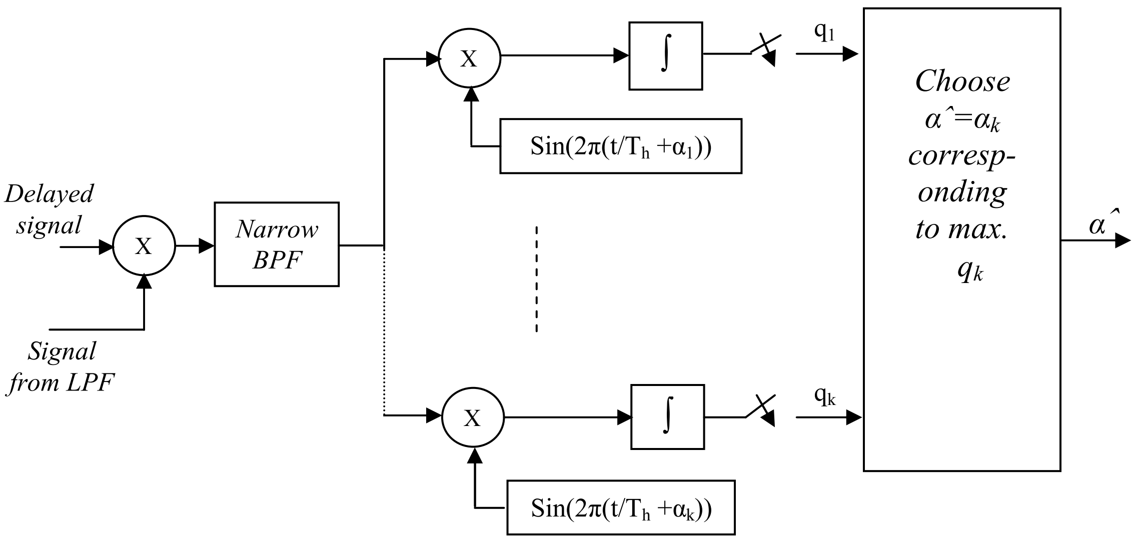

Fig (3b) Expanded multiple stage frequency hopping hop rate detector EMS-FH-HRD

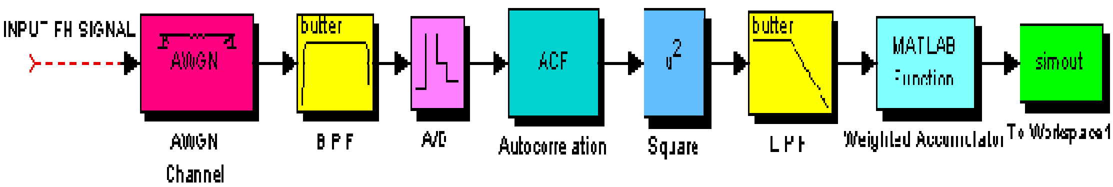

Fig (4) Simulation model for the SHAC estimator

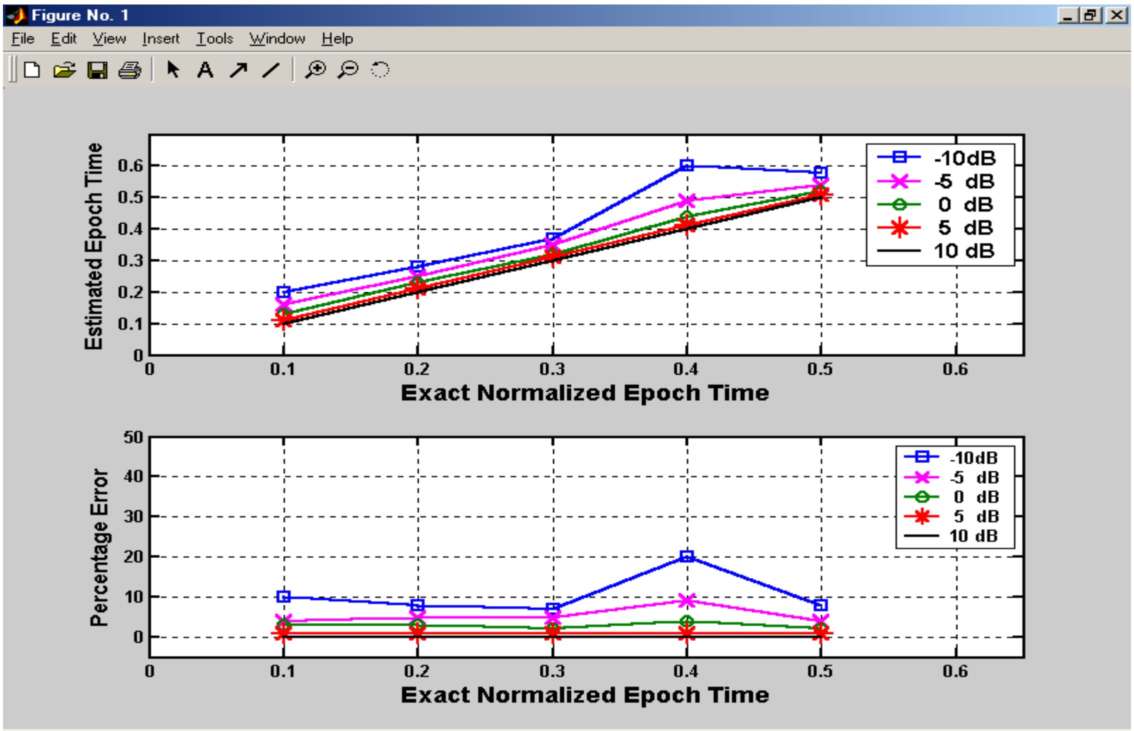

Fig (5) Exact, estimated epoch time, and the percentage error for different SNR

6. Computer Simulation for the Epoch Time Estimation Based on EMS-FH-HRD

The simulation model for this estimator is shown in Fig (6). After the value of the hopping rate was known exactly by using MS-FH-HRD, the delay Th/2 adjusted to this true value. Before the narrow bandpass filter the multiply operation produces a dc biased square wave at the hop rate whose first harmonic has zero crossings that are synchronous with the hop transition instants. Extracting this harmonic with a narrow bandpass filter and then processing this signal by a phase estimator produces the desired hop timing epoch estimate.

The bandwidth of the lowpass filter preceding the delay and multiply operation should be optimized to provide the best performance. This filter bandwidth results in the best compromise between (signal **.** signal) envelope distortion and reduction of the power in the (signal **.** noise) and (noise **.** noise) components that arise as a result of the square low operations following the bandpass filters. The phase estimator shown in Fig. (6) consists of nine branches. Each one contains a reference signal with a frequency equal to the hop rate and an appropriate phase value differs from one branch to another. In the first it is equal 0.1 rad./sec. , and in the second is equal to 0.2 rad./sec., and so on. The values that exterior from the integrator will be sampled and compared. The maximum one will be chosen. The number shown in the display refers to the branch that gives maximum output. Thus, the value of the phase difference in this branch is corresponding to the value of the estimated epoch time. Fig (7) shows the exact and the estimated values and the error percentage of the epoch time for 100 hop/sec. The error occurs at SNR= -10 dB, while it is equal to zero at SNR = (10, 5, 0,-5) dB. Fig (8) shows the same above case, but for 10 hop/sec. The error is very low at SNR= -10dB and equal to zero at SNR = (10, 5, 0, -5) dB.

7. Conclusions

Two simulation models have been used to estimate the epoch time parameter for a FH received signal SHAC and EMS-FH-HRD. For SHAC the range taken for normalized epoch time α is 0.1 to 0.5 and T_h= 0.01. The results are acceptable up to α < 0.4 and there is an estimation ambiguity when α > 0.5. The percentage error is increased when the SNR is decreased. The EMS-FH-HRD also gives acceptable results for different SNR and the percentage error was low for SNR equal to (-10dB). Furthermore, there is no error for other values of SNR for both case (100 hop/sec and 10 hop/sec). The advantage of this epoch time estimator over SHAC is that it could estimate the normalized epoch time (α) from 0.0 to 0.9 and with very low percentage error .

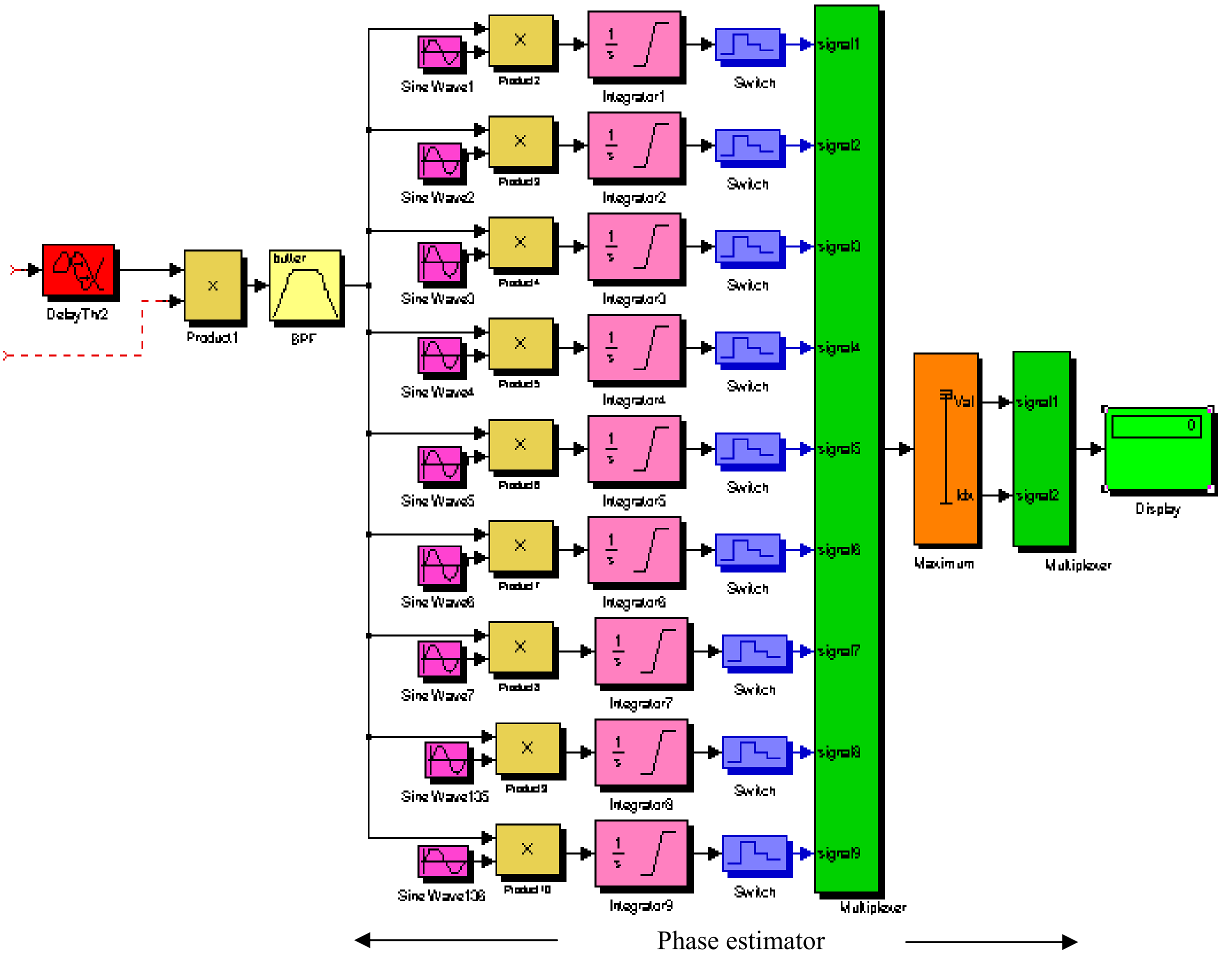

Fig (6) Simulation model for the Expanded Multiple Stage EMS-FH-HRD

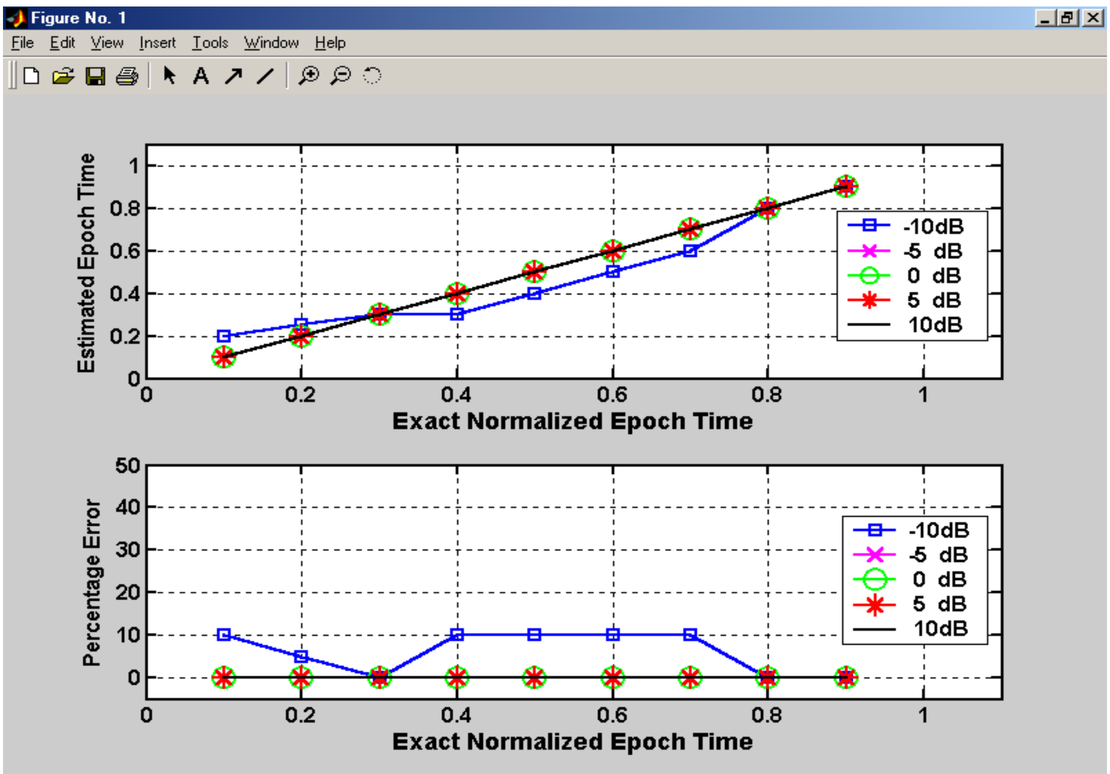

Fig (7) Exact, estimated normalized epoch time, and the percentage error for (100) hop/sec

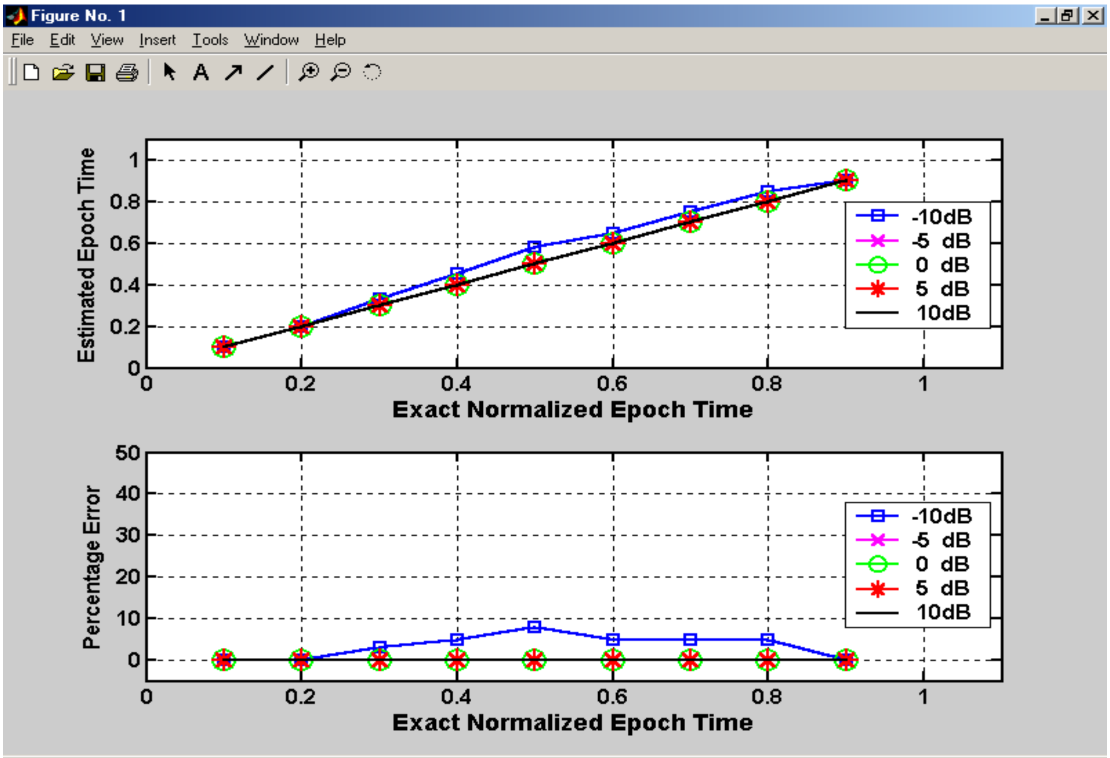

Fig (8) Exact, estimated normalized epoch time, and the percentage error for (10) hop/sec

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