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Frequency Hopping Spread Spectrum: An Effective Way to Improve Wireless Communication Performance

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1. Introduction

To improve the performance of short-range wireless communications, channel quality must be improved by avoiding interference and multi-path fading. Frequency hopping spread spectrum (FHSS) is a transmission technique where the carrier hops from frequency to frequency. For frequency hopping a mechanism must be designed so that the data can be transmitted in a clear channel and avoid congested channels. Adaptive frequency hopping is a system which is used to improve immunity toward frequency interference by avoiding using congested frequency channels in hopping sequence. Mathematical modelling is used to simulate and analyze the performance improvement by using frequency hopping spread spectrum with popular modulation schemes, and also the hopping channel situations are investigated.

In this chapter the focus is to improve wireless communication performance by adaptive frequency hopping which is implemented by selecting sets of communication channels and adaptively hopping sender's and receiver's frequency channels and determining the channel numbers with less interference. Also the work investigates whether the selected channels are congested or clear then a list of good channels can be generated and in practice to use detected frequency channels as hopping sequence to improve the performance of communication and finally the quality of service.

The Fourier transform mathematical modules are used to convert signals from time domain to frequency domain and vice versa. The mathematical modules are applied to represent the frequency and simulate them in MATLAB and as result the simulated spectrums are analysed. Then a simple two-state Gilbert-Elliott Channel Model (Gilbert, 1960; Elliott, 1963) in which a two-state Markov chain with states named "Good" and "Bad" is used to check if the channels are congested or clear in case of interference. Finally, a solution to improve the performance of wireless communications by choosing and using "Good" channels as the next frequency hopping sequence channel is proposed.

2. Review of related theories

2.1 Spread spectrum

Spread spectrum is a digital modulation technology and a technique based on principals of spreading a signal among many frequencies to prevent interference and signal detection. As

the name shows it is a technique to spread the transmitted spectrum over a wide range of frequencies. It started to be employed by military applications because of its Low Probability of Intercept (LPI) or demodulation, interference and anti-jamming (AJ) from enemy side. The idea of Spreading spectrum is to spread a signal over a large frequency band to use greater bandwidth than the Data bandwidth while the power remains the same. And as far as the spread signal looks like the noise signal in the same frequency band it will be difficult to recognize the signal which this feature of spreading provides security to the transmission.

Compared to a narrowband signal, spread spectrum spreads the signal power over a wideband and the overall SNR is improved because only a small part of spread spectrum signal will be affected by interference. In a communication system in sender and receiver sides' one spreading generator has located which based on the spreading technique they synchronize the received modulated spectrum.

2.2 Shannon capacity and theoretical justification for spread spectrum

Claude Shannon published the fundamental limits on communication over noisy channels in 1948 in the classic paper "A Mathematical Theory of Communication". Shannon showed that error-free communication is possible on a noisy channel provided that the data rate is less than the channel capacity. Shannon capacity (data rate) equation is the basis for spread spectrum systems, which typically operate at a very low SNR, but use a very large bandwidth in order to provide an acceptable data rate per user. Applying spread spectrum principles to the multiple access environments is a development occurring over the last decade (Bates & Gregory, 2001).

The Shannon equation states that the channel capacity "C" (error free bps) is directly proportional to the bandwidth "B" and is proportional to the log of SNR. Shannon capacity applies only to the additive white Gaussian noise (AWGN) channel. The channel capacity is a theoretical limit only; it describes the best that can possibly be done with any code and modulation method.

The basis for understanding the operation of spread spectrum technology begins with Shannon/Hartley channel capacity theorem:

$$C = B \times \log_2(1 + S / N) \quad (1)$$

In this equation, C is the channel capacity in bits per second (bps), which is the maximum data rate for a theoretical bit error rate (BER). B is the required bandwidth in Hz and S/N is the signal to noise ratio. Assume that C which represents the amount of information allowed by communication channel, also represent the desired performance. S/N ratio expresses the environmental conditions such as obstacles, presence of jammers, interferences, etc.

There is another explanation of this equation is applicable for difficult environments, for example when a low SNR caused by noise and interference. This approach says that one can maintain or even increase communication performance by allowing more bandwidth (high B), even when signal power is below the noise. In Shannon formula by changing the log base from 2 to e (the Napierian number) and noting that $\ln = \log_e$ Therefore:

$$C / B = (1 / \ln 2) \times \ln(1 + S / N) = 1.443 \times \ln(1 + S / N) \quad (2)$$

Applying the Maclaurin series development for

$$\ln(1+x) = x - x^2/2 + x^3/3 - x^4/4 + \dots + (-1)^{k+1} x^k/k + \dots \quad (3)$$

$$C/B = 1.443 \times (S/N - (S/N)^2/2 + (S/N)^3/3 - (S/N)^4/4 + \dots) \quad (4)$$

S/N is usually low for spread spectrum applications, considering that the signal power density can even be below the noise level. Assuming a noise level such that $S/N \ll 1$, Shannon's expression becomes simply:

$$C/B \approx 1.443 \times S/N \quad (5)$$

And very roughly:

$$C/B \approx S/N \text{ or } N/S \approx B/C \quad (6)$$

To send error free information for a given noise to signal ratio in the channel, therefore, one need only perform the fundamental spread spectrum signal spreading operation: increase the transmitted bandwidth.

2.3 Frequency hopping spread spectrum

Frequency hopping spread spectrum is a transmission technology used in wireless networks and a technique to generate spread spectrum by hopping the carrier frequency. FHSS uses narrow band signal which is less than 1 MHz, In this method data signal is modulated with a narrowband carrier signal that "hops" in random and hopping happens in pseudo-random "predictable" sequence in a regular time from frequency to frequency which is synchronized at both ends. Using FHSS technology improves privacy, it is a powerful solution to avoid interference and multi path fading (distortion), it decreases narrowband interference, increases signal capacity, improve the signal to noise ratio, efficiency of bandwidth is high and difficult to intercept also this transmission can share a frequency band with many types of conventional transmissions with minimal interference. For frequency hopping a mechanism must be defined to transmit data in a clear channel and to avoid the congested channels. Frequency hopping is the periodic change of transmission frequency and hopping happens over a frequency bandwidth which consists of numbers of channels. Channel which is used as a hopped channel is instantaneous bandwidth while the hopping spectrum is called total hopping bandwidth. Frequency hopping categorized into slow hopping and fast hopping which by slow hopping more than one data symbol is transmitted in same channel and by fast hopping frequency changes several times during one symbol. Hopping sequence means which next channel to hop; there are two types of hopping sequence: random hopping sequence and deterministic hopping sequence.

The focus of this work is on slow and deterministic frequency hopping sequence. In a frequency hopping network, there can be different number of receivers which one sender is designed as Base that is responsible to transmit the synchronization data to the receivers.

2.4 Adaptive frequency hopping

Adaptive frequency hopping (AFH) is a system in which devices constantly change their operating frequency to avoid interference from other devices and maintain security. AFH classifies channels as 'Good' or 'Bad' and adaptively selects from the pool of Good channels. 'Bad channels' means the channels with interference. The Idea of using AFH is to hop only

over Good and clear channels it means to choose the frequency channels that they have less interferences. For using AFH there must be a mechanism to choose 'Good' and 'Bad' channels. Using AFH has some advantages which they are:

- Active avoidance to narrowband interference and frequency fading
- Avoids crowded frequencies in hopping sequence
- Performance of BER is high
- Reduces transmission power
- Working with adaptive channel will further enhance system performance

RSSI (Received Signal Strength Indication) tells each channel quality to generate a list for 'bad channels'. As for using AFH there must be a mechanism to choose 'Good' and 'Bad' channels, this mechanism can be done by functionalizing one of the duplex channel as the feedback channel. The feedback information contains the channel numbers which are in use. In a duplex communication system as shown in Figure 1 there is a transmitter A and a receiver B to define as uplink and downlink from the sender to receiver and for the selection of frequency channel as the next hop to use the feedback from uplink. Also a system must be proposed to generate a hopping sequence number as the channel number which uplink "receiver" sends this number by the feedback to downlink "sender". Transmitter A baste on predefined frequency or control channel sends the data to receiver B, the RSSI value of downlink which is equivalent as SIR is measured at the end B. The receiver B analysis the data and sends a number to sender A over the uplink and if the measured data is below the criterion then LQA determines that channel needs to be switched. Sender A uses this number as a variable in a predefined algorithm which calculates the sequence of frequencies that must be used and sends a synchronization signal over downlink by the first frequency based on the calculated sequence to acknowledge the receiver side B that it has correctly calculated the sequence number. Finally communication starts between sender and receiver and both end receiver and sender change their frequencies based on the calculated order.

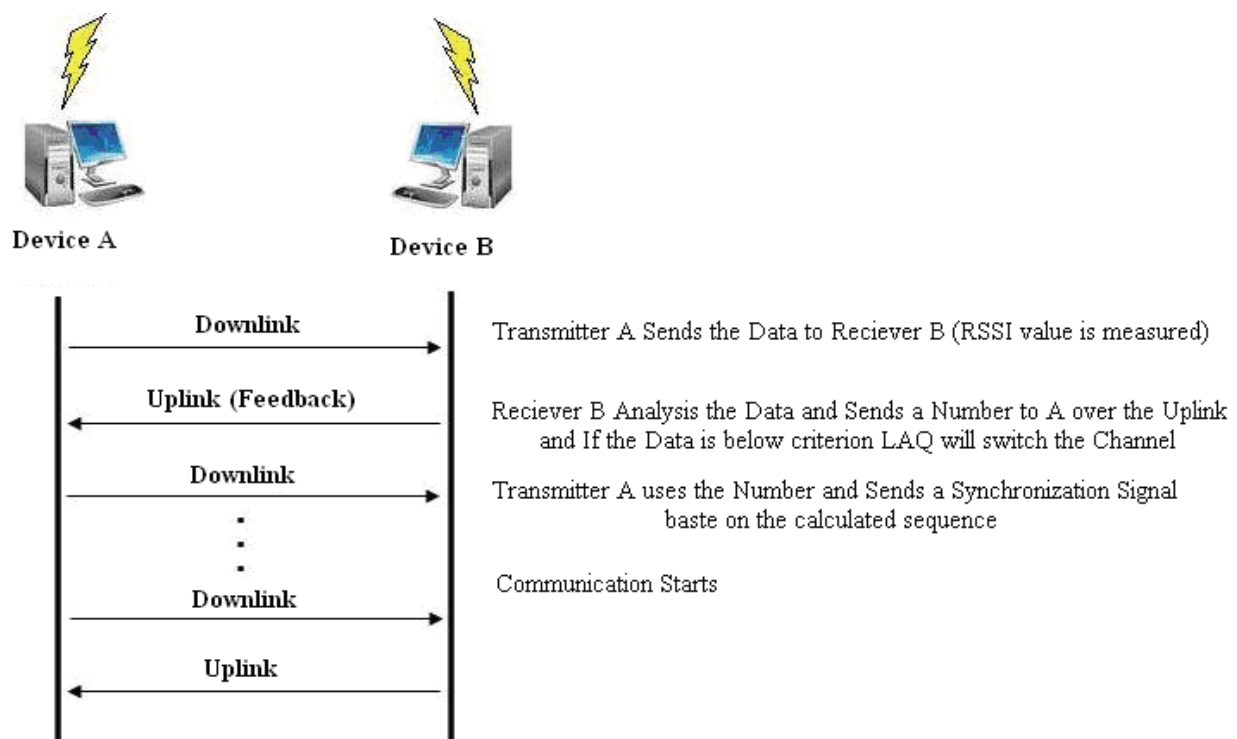


Fig. 1. Shows the communication scheme

To illustrate the system and principles of a proposed AFH scheme more, assume that there is a duplex transceiver system as shown in Figure 2. The system is an ordinary Frequency hopping system which uses a number of narrowband channels (Zander & Malmgren, 1995). As in Figure 2 HS is called Hope Sequence Generator, it generates pseudo-random symbols out of alphabet of size N_a . The generated sequence N_a is fed to the Mapping function that Maps incoming symbols onto a symbol alphabet of size N . And then these symbols are fed to the Frequency Hopper-Dehopper. The effect of these operations is that the system will use only N_a out of N available frequency at any time. The selection of which frequency to be used is made by LQA on the receiver side and since a duplex system is used the selected frequency is fed back to the transmitter side in the shape of a frequency map on the return channel.

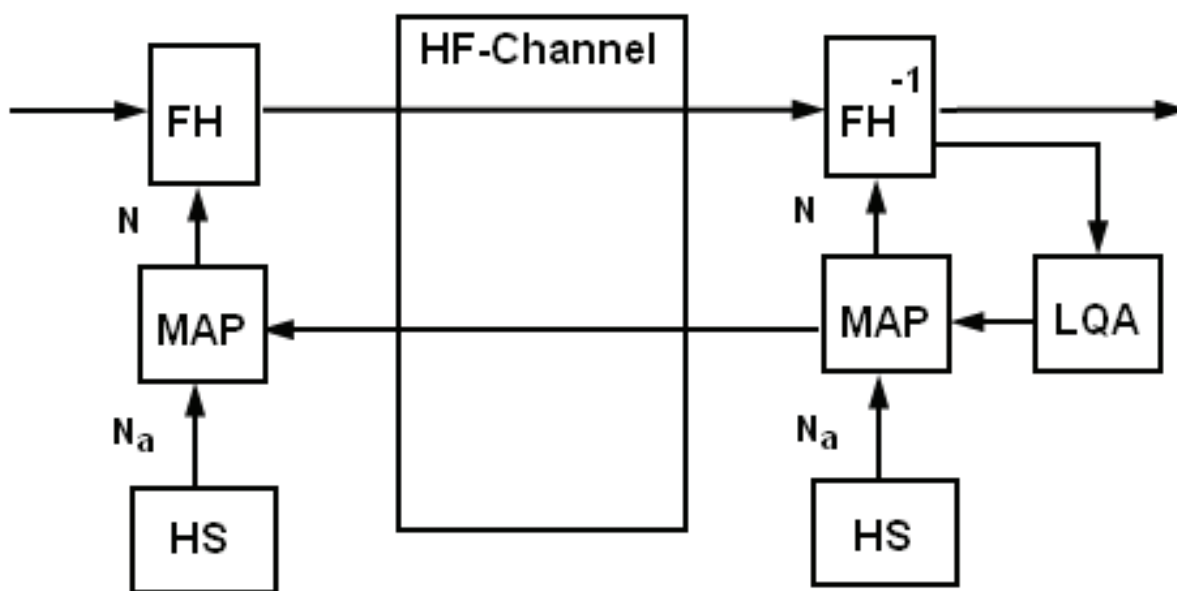


Fig. 2. Duplex transceiver system

To simplify the understanding of the AFH proposed system, assume a block-oriented transmission scheme is under use as shown in Figure 3.

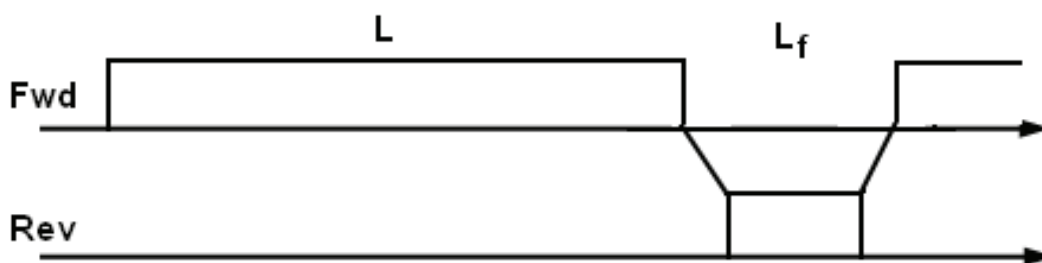


Fig. 3. Block-oriented transmission scheme

According to Figure 3, the transmitter transmits a frame of L chips which each contains one channel symbol. After the transmission of the block, the receiver performs its LQA and

replies by transmitting the new frequency map \mathbf{Lf} as a feedback block to be used in the subsequent (Forward) block transmission. It is important to mention that the proposed scheme the entire frequency map is transmitted at every updating instant and since the feedback channel is not perfectly reliable this procedure assures a high reliability. To generate a hopping sequence number as the channel number that uplink "receiver" sends this number by the feedback to downlink "sender" can be shown in a linear equation (Zander & Malmgren, 1995) and assuming binary transmission the size of the feedback block is:

$$\begin{aligned}
 C_f &= N_a \log_2 N + C_{OH} + R_x \\
 N &= \text{TotalAvailableChannels} \\
 N_a &= \text{ActiveChannels} \\
 C_f &= \text{ChipsOnFeedback} \\
 C_{OH} &= \text{FeedbackOverhead} \\
 R &= \text{ChipRate} \\
 \tau &= \text{propagationTime} + \text{LOADelay}
 \end{aligned}$$

LOH is feedback overhead which includes error detection symbols.

2.5 Channel and interference

Compared to the other kinds of wireless communications, high frequency (HF) communication is selectively fading because of the multipath propagation and abundance of interference from the others. Interference always exists in any wireless system. In the improved system bit error rate is highly important for the improvement of the communication systems. Every frequency channel due to interferences and fading shows different signal to noise ratio. In some of the frequency channels there are stronger SNR and these channels are more suitable for the transmission. Adaptive Frequency Hopping is a powerful solution and a technique that deals with different kind of interferences, noise sources and fading. For the simplicity of the work the focus will be only on the interference as the main disturbance in achieving a desired and suitable transmission quality and neglect all the other disturbance resources such as other noises and fading.

3. Markov chain

A Markov Chain process is a random process with the Markov property which means that given the present state the coming future states are independent from the past. Also the future states will be reached by probabilistic process and in every step the system may change its state from current state to another or remain in the same state, these changes in the states are called transitions and the probabilities are called transition probabilities.

Markov chain is formally presented as:

$$\Pr(X_{n+1} = x \mid X_n = x_n, \dots, X_1 = x_1) = \Pr(X_{n+1} = x \mid X_n = x_n) \quad (7)$$

A discrete time Markov Chains is a stochastic dynamical system in which the probability of arriving in a particular state at a particular time moment depends only on the state at the previous moment. That is:

1. States are discrete: $i = 0, 1, 2, \dots$
2. Time is discrete: $t = 1, 2, \dots$
3. Probabilities P_{ij} of transition from state i to state j in one time step are constant, i.e., they do not depend on time and do not depend on how the system got in state i "Markov property".

3.1 Gilbert-Elliot channel model

Bit error Models generate a sequence of noise bits (where 0's represent good bits and 1's represent bit errors) which to produce output bits modulo 2 to the input bits must be added. Models are grouped into two classes (Lemmon, 2002):

1. Memoryless Models
2. Models with Memories

In Memoryless Models the noise bits are produced by a sequence of independent trials that each trial has the same probability $P(0)$ of producing a correct bit and probability $P(1) = 1 - P(0)$ of producing a bit error.

The actual measurement from the communication channels indicate that these channels are with memories, for example the probability of 100's bit is erroneous is dependent on the 99's bit. For modelling of these kinds of probabilistic situations a commonly technique is used that is called Markov Chain, This technique helps to make the bit error probability depend on the states. The use of Markov Chain technique in bit error models was introduced by Gilbert-Elliot for the first time. Gilbert model based on Markov Chain has two states G (Good) and B (Bad or for Burst). In state G, transmission is error-free and in state B the link has probability h of transmitting a bit correctly. Figure 4 shows a transition diagram and bit error probabilities for Markov Chain. The situation of small p is where transition jumps from B to G and the capital P is where the probability of jumping from G to B. Also the states B and G tend to persist and the model simulates bursts of errors.

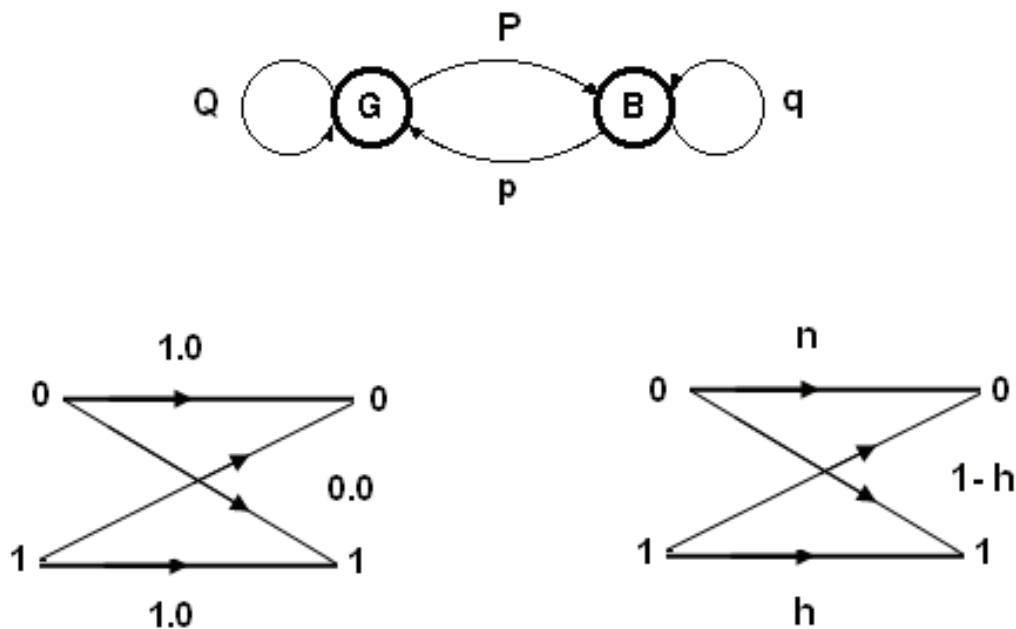


Fig. 4. Transition diagram and bit error probabilities model

The model has shown above is the transition diagram and bit error probability for Gilbert-Elliot Model and simply has three independent parameters (p , P and h) and also describes the error performance of wireless links.

The parameters p , P and h are not directly observable and must therefore be determined from statistic measurements of the error process and also important to note that Runs of G alternates with runs of B. The run length has geometric distributions, with mean $1/P$ for the G-runs and $1/p$ for the B-runs.

3.2 Geometric distribution

A Bernoulli process is a discrete time stochastic process consisting of sequence of independent random variables which take the values over two symbols, the general example for Bernoulli is coin tossing that's why it's said a Bernoulli process is coin flipping several times and also a variable in such a sequence called Bernoulli variable. Bernoulli distribution has two possible outcomes labeled by $n = 0$ and $n = 1$, in which $n = 1$ is 'Success' with probability p and $n = 0$ is 'Failure' occurs with probability $q = 1 - p$, where $0 < p < 1$. The performance of a fixed number of trials with fixed probability of success on each trial is known as a Bernoulli trial. The distribution of heads and tails in coin tossing is an example of Bernoulli distribution with $p = q = 1/2$.

Geometric distribution is number of Failures before the first success on sequence of independent Bernoulli trials. The geometric distribution is a discrete distribution for $n = 0, 1, 2 \dots$ having probability density function:

$$\Pr(X = x) = (1 - p)^{x-1} p \quad (8)$$

Also the mean value of x will be calculated as:

$$E[x] = \sum_{x=1}^{\infty} x \Pr(X = x) \quad (9)$$

Which is equal to $1/p$, also the Runs length of Good and Bad states can be expressed by geometric distribution in which for the Good runs, mean value of $1/P$ and for the Bad runs, the mean value of $1/p$ is used. Also the time fraction in both of Good and Bad states based on persistence in each state can be calculated for example the fraction of time spent in B state is:

$$P(B) = \frac{P}{P + p} \quad (10)$$

The sequence of states cannot be reconstructed from the sequence of bits in the error process, because both of 0's and 1's (The Good bits and bit errors) are produced in the B state and since bit errors happen only in state B with probability of $1-h$ then the probability of error is:

$$P(1) = P(1, B) = P(B)P(1 | B) = (1 - h) \frac{P}{P + p} \quad (11)$$

However the bits of the error process (Runs of 0's and 1's) and the distribution of run lengths of 0's (error Gaps) and 1's (error Bursts) are observable to determine model parameters.

3.3 Parameter estimation

The determination of the three parameters p , P , and h from measurements of the error process requires that parameters be expressed as functions of three other parameters that are directly observable and for Markov Chain parameter estimation the functions which have been proved formerly (Lemmon, 2002), that those are:

$$\mu_{EB} = \frac{1}{1-q(1-h)} \quad (12)$$

$$\mu_{EG} = \frac{h(1-Q) + (1-q)}{(1-h)(1-Q)[1-q(1-h)]} \quad (13)$$

$$\sigma_{EB}^2 = \frac{\sqrt{q(1-h)}}{1-q(1-h)} \quad (14)$$

$$\sigma_{EG}^2 = \frac{(1-h)(qJ + p - Q)J(J+1)}{[1-q(1-h)](J-L)(1-J)^3} + [J \leftrightarrow L] - \mu_{EG}^2 \quad (15)$$

In the equations μ_{EB} is the mean error burst length and μ_{EG} is the mean error gap length, σ_{EB}^2 is the variance of the error burst distribution and σ_{EG}^2 is the variance of error gap distribution. J and L are defined as:

$$2J = Q + hq + \sqrt{(Q + hq)^2 + 4h(p - Q)} \quad (16)$$

$$2L = Q + hq - \sqrt{(Q + hq)^2 + 4h(p - Q)} \quad (17)$$

4. Matlab modelling

4.1 Gilbert-Elliot modelling

Gilbert-Elliot channel model is used for modelling a telecommunication channel. For obtaining the parameters of this model, first a sequence of data bit is given to the transmitter and then from the receiver side the transmitted data is received as output data. With the input sequence and output sequence, bit error sequence can be calculated easily. By having this bit error sequence and the method of parameter estimation in Lemmon (2002) the model parameters can be calculated.

For this reason channel simulation is done with Simulink. To obtain the bit sequence of input and output, two variables with names "in" and "out" are used. With XORing the input and output bit sequences the bit error sequence is calculated. By setting bit error sequence at argument of function `marcov`, Markov parameters can be achieved from the output of function `marcov`. In function `marcov` by using the function `coef`, the sequence of error burst and error gap can be calculated. After calculation of statistical parameters of these two sequences, Markov parameters can be then calculated by function `fsolve` which solves nonlinear equations.

4.2 Defining Markov chain parameters

To obtain Markov parameters in Matlab, a function of `marcov` is created as follow.

```
error_seq= xor(in,out);
z=marcov(error_seq);
z=fsolve(@solv,[.1 .1],[],meb,meg,veg);
```

In this function the error sequence is first inputted to the function of `coef` then the output of sequence is obtained as 0's and 1's.

For example assume there is a sequence of:

```
error_seq = [0 1 0 0 1 1 1 0 1 1 0 1 0 1 1 1 1 0 0 0]
```

Then at the output of function `coef` will obtain:

```
error_burst_seq = [1 3 2 1 4]
```

```
error_gap_seq = [1 3 1 1 1 3]
```

Now from the output `error_burst_seq` and `error_gap_seq` which is the sequence of error runs it can be seen that the length of the run of the errors has come in order of their happenings. Next step is to calculate the mean value and the variance of the sequence.

4.3 Channel performance evaluation

100 communication channels are evaluated and channel performances are categorized based on Gilbert-Elliot channel model. Gilbert-Elliot model is used for modelling a real communication channel and evaluating the performance of the channels, in which first a bit sequence is sent through a channel and then its bit error sequence is computed. Using bit error sequence helps to find out the parameters of the model. Markov parameters can be used to find following two functions: Fraction of time spent in state B (Bad) from equation (10) and probability of the error from equation (11).

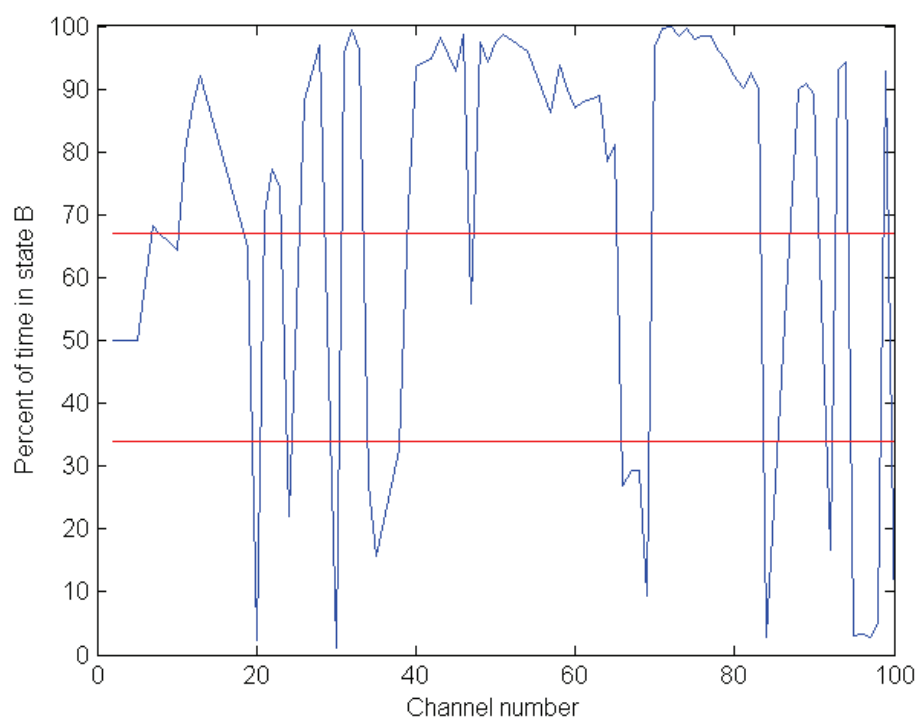


Fig. 5. Percent of time that each channel spends in state B

To evaluate the channel performance based on Gilbert-Elliot Markov chain model the information about bit error sequence is collected to simulate the channel model with Matlab. Additive white Gaussian noise (AWGN) channels with 100 random input powers are used in simulation.

First the percent of time is computed which each channel spends in state B or in the other word the probability of being in state B that multiplied by 100. Figure 5 shows the result of each channel being in Bad state.

The achieved result from Figure 2 helps to categorize the Channels based on three different groups as “Bad Channels”, “Good Channels” and “Very Good Channels” by identifying two threshold values and categorizing those decides to transmit data over “Very Good” and “Good” channels then by such transmission the performance of the communication system can be improved. Then the error probability in Bad state for each channel is computed. Figure 6 shows these probabilities for 100 different channels.

4.4 Testing

Gilbert-Elliot channel model is used to simulate the error process and correctly reproduce all of its statistical properties. To validate the model, the error process generated by the model must be compared to the measured error process. For testing, the program bit error sequence is generated using Markov chain model. Two programs are made as follow: `marcov_gen` is a bit error sequence generator for Markov parameters and `marcov_test` tests the bit error sequence and the output is displayed in workspace.

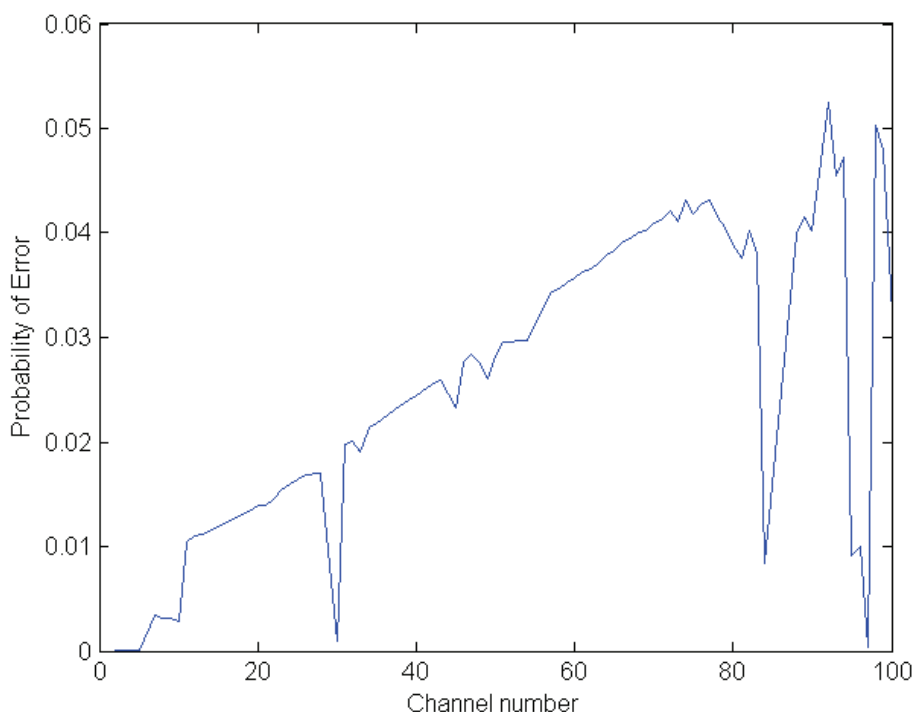


Fig. 6. Error probability being in Bad state for each channel

The objective of the parameter estimation is to choose values of the model parameters that generate error burst and error gap distributions that reassembles the corresponding

measured distributions as close as possible. Therefore for testing the mean and variance of error burst and error gap of regenerated error sequence are calculated and compared by statistical parameters of channel bit error sequence, where the result is shown in Table 1.

	error burst mean	error gap mean	error gap variance	
SNR = 3dB Input power = 1	1.0568	18.1134	319.4516	A
	1.0492	18.4713	319.3184	B
SNR = 3dB Input power = 2	1.1456	7.7868	48.9981	A
	1.1500	8.0421	55.0026	B
SNR = 3dB Input power = 3	1.2201	5.6570	25.5754	A
	1.2271	5.5166	24.5044	B

A: Statistical parameters channel error sequence.

B: Statistical parameters of regenerated error sequence.

Table 1. Statistical parameters of channel error and regenerated error sequence

For testing, first Markov model parameters of a channel error sequence are computed, then a sequence of the model is generated and statistical parameters are computed. The statistical parameters must be as equal as channel error sequence. It is important to mention that first state of the Markov model in function `marcov_gen` chooses the probability 0.5, so sometimes two different answers can be seen and that the nearest one to the error sequence statistic is the correct one.

5. Evaluation of frequency hopping

To design the frequency hopping (FH) model, MATLAB Simulink has been used. The spreader at transmitter section is an M-FSK modulation but the input of the modulator is hopping index. This section consists of a PN Sequence Generator, an Assemble Packets block and a Goto block as shown in Figure 7.

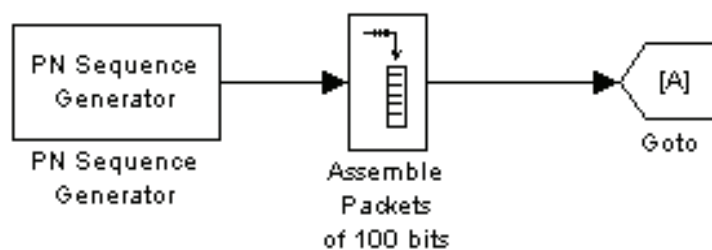


Fig. 7. Model of frequency hopping in Simulink

The design of frequency hopping spreader is shown in Figure 8. The spreader part consists of M-FSK modulator base (with M equal to 64), a From block (Hop index that is created in previous step), a To Frame block and a Multiplication block. The block parameter of FSK modulator is 64 in M-FSK number and it means that there are 64 hopping sections. These sub-bands are selected by the hop indexes.

The design of frequency hopping despreader, is the same as spreader section but the output of M-FSK modulator block is complex conjugated as shown Figure 9.

This frequency hopping model is used for evaluation of three different modulations: QAM, QPSK, GFSK, and compares the performance with the situation without frequency hopping. Performance evaluation is based on BER values under two situations (with and without FH) versus normalized signal-to-noise ratio (SNR) measured by E_b/N_0 values of the channel, as shown in Figure 10, 11, 12.

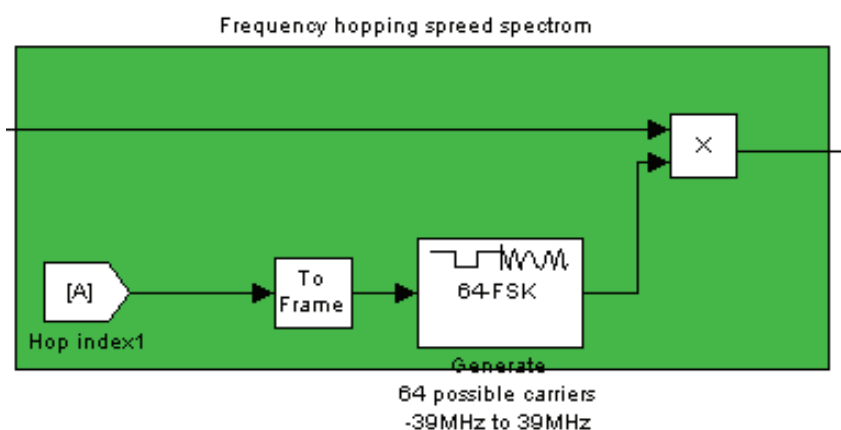


Fig. 8. Design of frequency hopping spreader

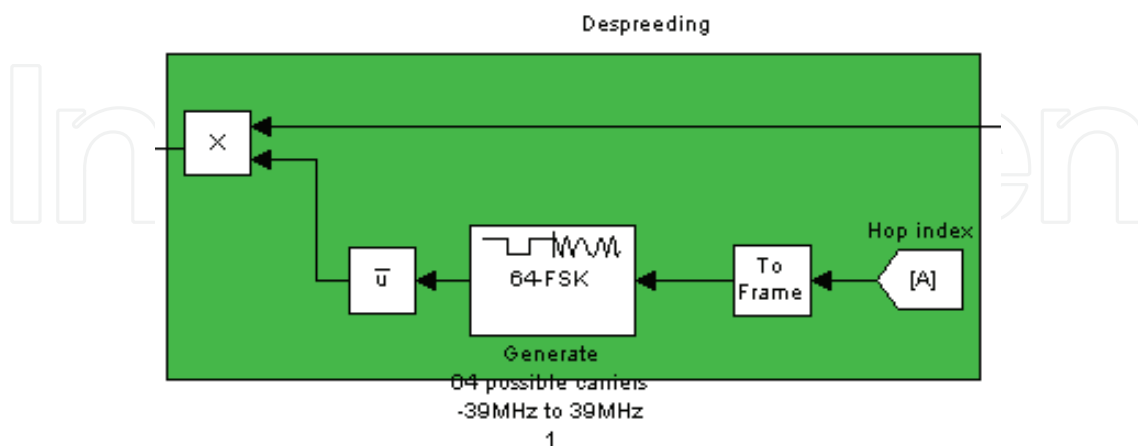


Fig. 9. Design of frequency hopping despreader

From Figure 10 it can be seen that applying FH with QAM modulation does not lead to a sensible improvement in performance or significant reduction of BER. From Figure 11 it can be seen that applying FH with QPSK modulation gives a good result and reduces

significantly BER compared to without FH at same level of SNR. From Figure 12 it can be seen that applying FH with GFSK modulation reduces dramatically BER compared to without FH at same level of SNR and lead to a much higher performance.

In overall, based on the evaluation results it can be concluded that applying the designed FH schemes with certain modulations can improve their communication performances, especially at weak SNR levels as most cases of short range wireless communications have.

6. Conclusion

As a result of the work it can be concluded that adaptive frequency hopping is a powerful technique to deal with interference and Gilbert-Elliot channel model is a good technique to analyze the situations of channels by categorizing the channel conditions based on their performance as Good or Bad, and then apply adaptive frequency hopping which hops frequencies adaptively by analyzing the state of the channel in case of environmental problems such as interferences and noises to improve the communication performance.

Frequency hopping spread spectrum is modelled with MATLAB and three different modulations i.e. QAM, QPSK and GFSK are studied to investigate which of these modulations are good to apply with FHSS model. The simulation results show that applying FHSS with QAM modulation dose not lead to a remarkable reduction of BER, but with QPSK modulation gives a good result and reduces BER at lower SNR, while in GFSK modulation shows a significant reduction of BER and lead to a high performance.

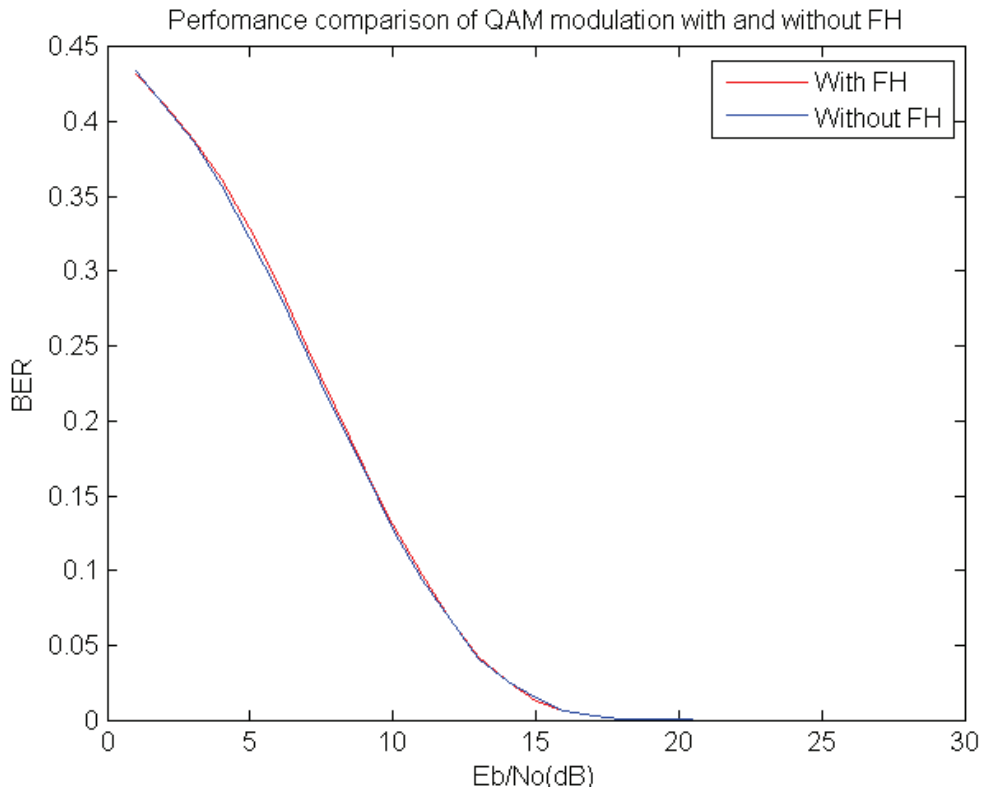


Fig. 10. QAM modulation

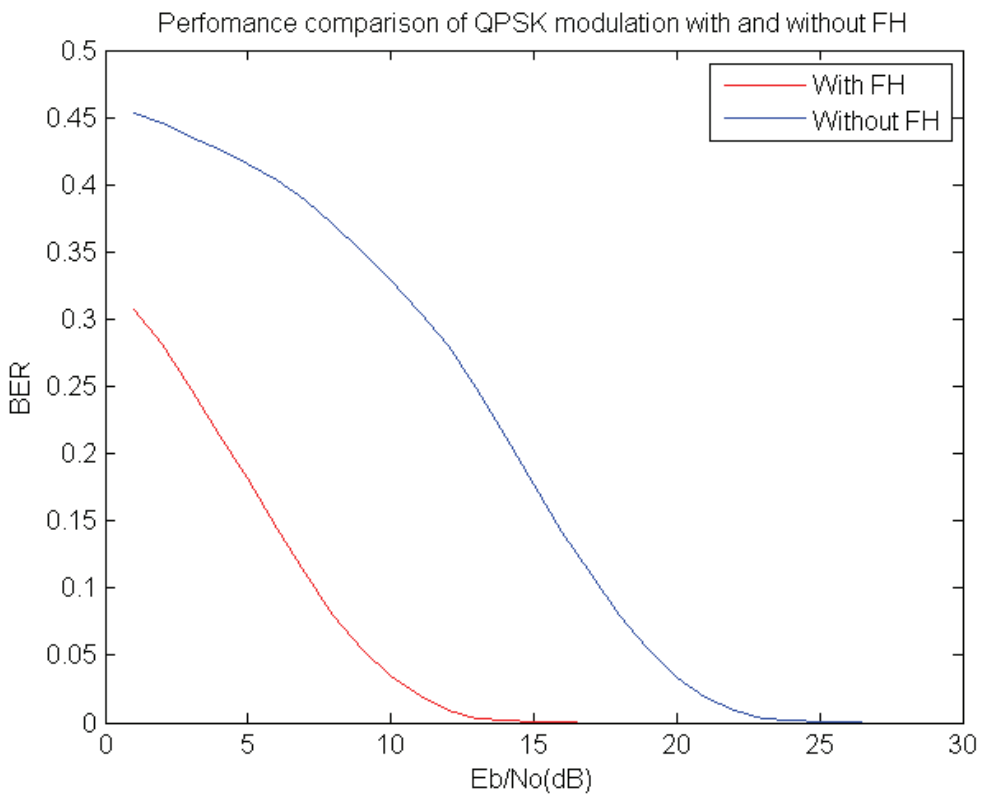


Fig. 11. QPSK modulation

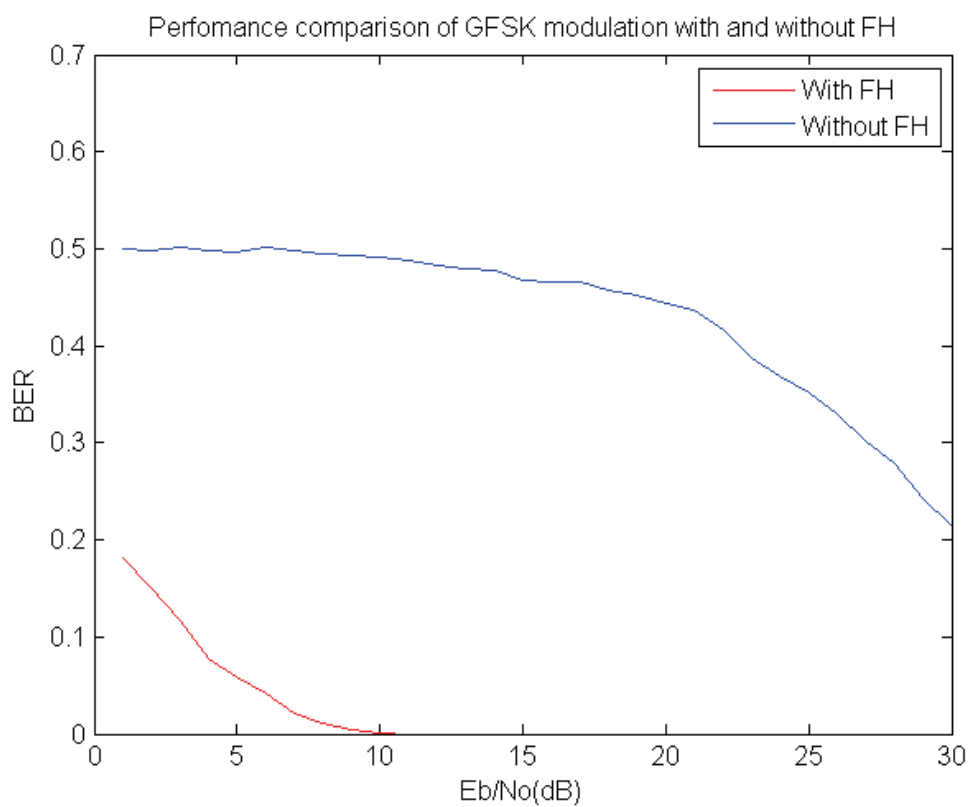


Fig. 12. GFSK modulation

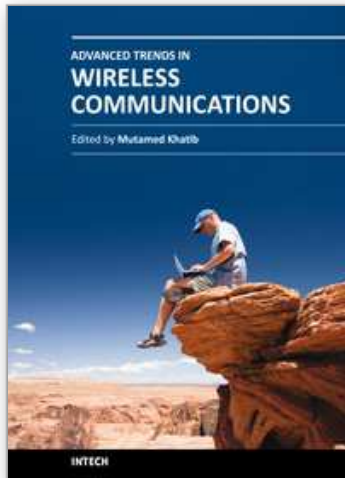
7. Acknowledgement

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Physical limitations on wireless communication channels impose huge challenges to reliable communication. Bandwidth limitations, propagation loss, noise and interference make the wireless channel a narrow pipe that does not readily accommodate rapid flow of data. Thus, researches aim to design systems that are suitable to operate in such channels, in order to have high performance quality of service. Also, the mobility of the communication systems requires further investigations to reduce the complexity and the power consumption of the receiver. This book aims to provide highlights of the current research in the field of wireless communications. The subjects discussed are very valuable to communication researchers rather than researchers in the wireless related areas. The book chapters cover a wide range of wireless communication topics.

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