Design and Implementation of FHSS and DSSS for Secure Data Transmission

M. Hasan, J. M. Thakur, and P. Podder
Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh
Email: {mehedihasanece, jagmohanthakur43, prajoypodder}@gmail.com

***Abstract*—With the growing advancements in the field of technology in this modern world, digital communication systems are increasing attractively and flexible for a secure form of data communication. Spread Spectrum overcomes the severe levels of interference that are encountered in the transmission of the digital information and rely upon shift register codes. Spread spectrum technology has blossomed from a military technology into one of the fundamental building blocks in current and next-generation wireless systems. From cellular to cordless to wireless local area network (WLAN) systems, spectrum is a vital component in the system design process. It has found important commercial applications in CDMA cellular networks as well as wireless personal communication networks. This paper mainly focuses the design of spread spectrum techniques, namely Direct Sequence Spread Spectrum (DSSS) and Frequency Hopped Spread Spectrum (FHSS) which involve for spreading the bandwidth of the signal to minimize the troubles that can arise from the vulnerabilities of conventional circuits through the channel.**

***Index Terms*—direct sequence spread spectrum (DSSS), frequency hopping spread spectrum (FHSS), FFT, modulation technique, PN sequence, spreading code, spread spectrum (SS)**

I. Introduction

Short range wireless communications performance is improved by making channel quality free from interference and multipath fading. In Spread spectrum transmission, a signal occupies larger bandwidth than of minimum necessary bandwidth to send the original information. The spreading of the band is obtained by means of a sequence or code independent of data, while synchronized reception code at the receiver is used for subsequent data recovery and dispreading [1]. Spread spectrum has a different method like direct sequence spread spectrum (DSSS), frequency hopping spread spectrum (FHSS), Time hopping spread spectrum (THSS) and a hybrid of these, which are used for multiple accesses. Main advantages of spread spectrum (SS) are: Security, Message Privacy, Resolution Ranging, Low Probability of Intercept, CDMA, Anti-jamming and High Anti-interference. From [2], the privacy of the transmission is obtained. Spread spectrum system is a wireless digital communication system which is designed to overcome a jamming situation that is, when an opposition party can interrupt the communication [3]. Cordless phones were used before the entry of Spread spectrum (SS), but due to a variety of reasons as in [4]-[6] they become outdated, especially with the entry of spread spectrum. More details on Spread spectrum (SS) history are available in [7]-[9]. However, the SS technology was first developed for military applications, but today its commercial applications include Bluetooth, WPAN, wireless LANs, global positioning system, cordless telephones and cellular telephones. The two most fundamental methods of spread spectrum are direct sequence spread spectrum and frequency hopping spread spectrum are used due to various reasons such as: low emission energy, the potential interference can be decreased and secure communications low using SS, multiple access ability between a number of users, detection probability, low emission energy, robustness, security of a medium, detection probability, anti-jamming the communication, noise and decreasing the interference etc. [10]. These spreads spectrum methods are used mainly for Police Radar and military communications [11], while the IEEE 802.11 wireless LAN uses these spread spectrum techniques in the 2.4 GHz ISM band [12].

The rest of the paper is organized as follows. Architectural view for secure data transmission is described on Section-II. Under this section, PN Sequences, Spread Spectrum (SS), Direct Sequence Spread Spectrum system (DSSS), Frequency Hopping Spread Spectrum system (FHSS). Modulation technique for SS, DSSS and FHSS are described in Section-III clearly. The experimental results and comparison is discussed in Section-IV. Finally, Section-V concludes the paper.

II. Architectural View for Secure Data Transmission

A. PN Sequences

PN sequences are deterministic, periodic and binary sequences with a noise like wave form. It is also called Pseudo random noise as it seems random for the user who has no idea about the code. The longer the period of PN spreading code, the harder will be the detection of the sequence (Fig. 1). This sequence is generated by feedback shift registers which is made of m flip-flops with two states memory stages.

Manuscript received June 18, 2014; revised December 20, 2014.

doi: 10.12720/ijsps.4.2.144-149

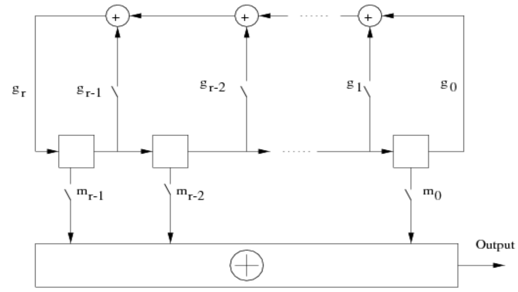


Figure 1. Architecture of PN sequence

B. Spread Spectrum

Bandwidth and signal power plays an important role in any digital communication systems. These two key parameters must be improved to reach effective performance and efficient communication. But, in some cases, this efficiency must be sacrificed to provide security which is a significant objective in communications. There is no usage of system, if messages are detected by unwanted listeners. The major advantage of Spread Spectrum (SS) is the ability to reject interferences whether it is the unintentional interference that can be occurred due to another user trying simultaneously to transmit over the channel or the intentional interference (i.e. another trying to jam the transmission). A spread spectrum modulation scheme is a digital modulation technique that utilizes a transmission bandwidth much greater than the modulating signal bandwidth, independently of the bandwidth of the modulating signal. There are several reasons why it might be desirable to employ a spread spectrum modulation scheme. Among these are to provide resistance to unintentional interference and multipath transmissions, resistance to intentional interference, signal with sufficiently low spectral level so that it is masked by the background noise and to provide a means for measuring range between transmitter and receiver. Fig. 2 shows the block diagram of a spread spectrum system.

Spread Spectrum modulation can be described in two ways:

- The signal occupies a minimum bandwidth which is necessary to send the information.
- Spreading is done by means of spreading signal which is independent of the data and dispreading is accomplished by the correlation of the received spread signal with a synchronized replica of the spreading signal used to spread the information.

There has been an ongoing discussion concerning which spread spectrum technique to prefer in military systems. Spread spectrum dependent on a variety of factors given by the operational environment. Characterizing the environment and establishing consensus about the relative importance of the various factors influencing a system is usually a difficult task, particularly since some of these factors are largely dependent on conditions like geographical and topographical placement which are not fixed for mobile users. Some of the factors to consider are [13], [14]:

- Teleservices to support;
- Capability or co-existence with other systems;
- Operational area (urban environments or rural areas);
- Doppler frequency shifts caused by relative motions;
- Interference, both narrowband and wideband;
- Fading characteristics;
- Severe specular multipath;
- Necessity for message integrity;
- Response (blind acquisition required);
- Etc.

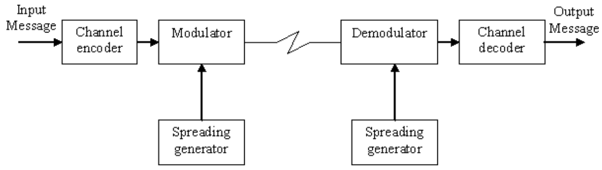


Figure 2. Architecture of spread spectrum (SS)

Spread Spectrum is a very convenient technology possessing the following advantages:

- Interference suppression.
- Cross talk minimization.
- Reduction of signals energy density
- Multiple channel accesses.
- Fine time resolution.

There are two techniques widely used as Spread Spectrum (SS) modulation techniques: Direct Sequence Spread Spectrum (DSSS) and Frequency Hopped Spread Spectrum (FHSS). Both methods can operate in presence of noise like spreading code called pseudo random sequence.

C. Direct Sequence Spread Spectrum System

In case of direct sequence spread spectrum (DSSS), each bit in the original signal is denoted by multiple bits in the transmitted signal using a spreading code. The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used. Therefore a 10-bit spreading code spreads the signal across a frequency band that is 10 times greater than a 1-bit spreading code. In the transmitter stage, the baseband data signal m (t) is spread using PN-Sequence c (t). Then, the resultant spread signal s (t) is applied to BPSK modulator. The output signal of the BPSK modulator x (t) is transmitted over AWGN channel.

In the receiver, the received signal is demodulated by using coherent detector and then it is multiplied again by the same (synchronized) PN code. Since the code existed of +1s and −1s, this operation completely removes the code from the signal and the original data signal is left. Another observation is that the de-spread operation is the same as the spread operation.

Fig. 3 shows a simplified view of direct sequence spread spectrum (DSSS). A DSSS radio works by mixing a PN sequence with the data. This mixing can be done by generating a wideband signal which is used to modulate the RF carrier, s(t)=m(t)+c(t). s(t) is then fed to the BPSK modulator input. On the receiver side the coherent detector input is y(t)=n(t)+x(t), where n(t) is the additive white Gaussian noise.

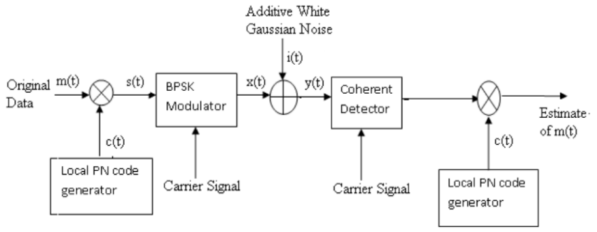


Figure 3. Functional blsock diagram of direct sequence spread spectrum (DSSS).

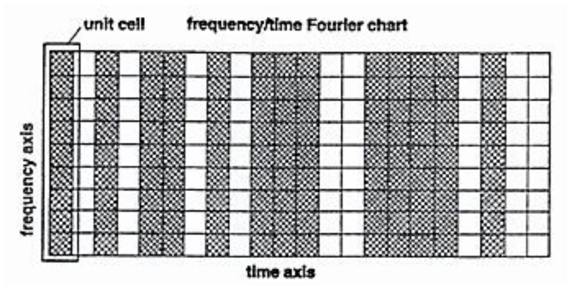


Figure 4. Multitime hopper or direct sequence coding schme. This system gives full coding along the time axis, but no independent structuring along the frequency axis.

Fig. 4 provides a Multitime hopper or direct sequence coding schme. A DSSS radio works by mixing a PN sequence with the data [14]. This mixing can be done by generating a wideband signal which, in turn, is used to modulate the RF carrier. It can also be done, which is actually more common, by modulating the carrier source with the data and then spreading the signal prior to transmission. In either case, the mixing is usually performed digitally. On the receiver side, the incoming DS signal is despread by generating a local replica of the transmitter's PN code. The signal is then synchronised with this local PN sequence. The multiplication or remodulation of the incoming signal by the local PN sequence collapses the spread signal into a data modulated carrier by removing the effects of the spreading sequence. Signal similarity is measured by the correlation technique and the identity of a signal that has been spread with a particular PN sequence can be discovered.

DSSS is a very useful technology with the following advantages:

- System collocation.
- Noise and interference immunity.
- Multipath immunity.
- Security purpose.
- Bluetooth interference.

D. Frequency Hopping Spread Spectrum System

Near far effect is the main problem in Direct Sequence spreading, which is less in FHSS. Frequency Hopping Spread Spectrum is a type of spread spectrum (from Fig. 5), in which the carrier hops randomly from one frequency to other with respect to time. In FHSS, the input carrier frequency to the modulator itself varies within a fixed bandwidth. With respect to time the frequency assigned for modulation is changed with a central frequency but with a fixed bandwidth. As the frequencies change from one to another and the allocation of frequency is Pseudorandom, i.e. not in order (dependent upon a PN sequence). By this carrier frequency hopping, obviously the bandwidth of the signal is increased [14], [15].

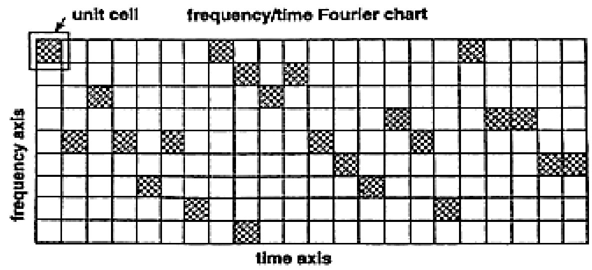


Figure 5. Frequency hopping coding scheme

The two basic classifications of frequency hopping are:

- Slow-frequency hopping: in which the symbol rate Rs is multiple of hop rate Rh.
- Fast-frequency hopping: in which the hop rate Rh is multiple of symbol rate Rs.

Fig. 6 shows the general scheme of FHSS modulation. A PN sequence generator creates a k-bit pattern for every hopping period Th. The frequency synthesizer creates a carrier signal of different frequencies, and the carrier signal is modulated by the source signal. At receiver, the received signal is first de-spread using same PN sequence and then demodulated to get the estimated data. The carrier frequency used for frequency modulation is here dynamically determined by the PN sequence generator as discussed in the previous section. The modulated signal can be send to the mixer to spread the using locally generated PN-sequence. The resultant signal is responsible for instantaneous transmission bandwidth.

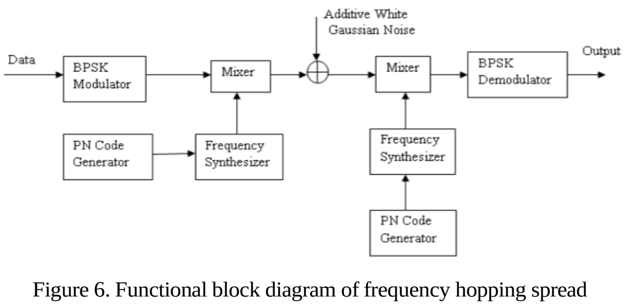


Figure 6. Functional block diagram of frequency hopping spread spectrum (FHSS)

III. Overview of Modulation Process

A. Spread Spectrum System

Spread Spectrum modulation techniques are composed of two consecutive modulation processes executed on the carrier signal (Fig. 7):

- Process 1 - Executed by the spreading code .It is this spreading process that generates the wide bandwidth of the transmitted signal.

- Process 2 - Executed by the message to be transmitted. Suitable modulation techniques can be used on the input message.

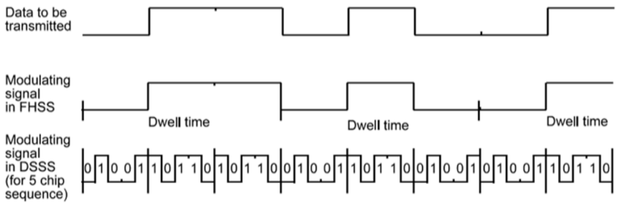


Figure 7. Modulation process of SS, DSSS, FHSS

B. *Direct Sequence Spread Spectrum System*

In DSSS systems, the two modulation processes are as follows[15], [16]:

- Process 1 - Spreading code modulation

The original message is modulated by the spreading code. In DSSS systems, the spreading code is a sequence of bits (known as chips), and the first modulation step is an exclusive=OR (XOR) operation executed between the message and the spreading code (in a process known as chipping). The result of the first modulation step is that a 0 bit of message is converted into a chip sequence representing the 0 bit, and the 1 bit of message is converted into an another chip sequence, representing the 1 bit. Instead of transmitting the original message bit, a chip sequence representing the bit will be transmitted.

- Process 2 - Message modulation

The sequences representing the message bits modulate the carrier signal.

- Redundancy is achieved by the presence of the message bit on each chip of the spreading code. Even if some of the chips of the spreading code are affected by noise, the receiver may recognize the sequence and take a correct decision regarding the received message bit.

C. *Frequency Hopping Spread Spectrum System*

- Process 1 - Spreading code modulation

The frequency of the carrier is periodically modified following a Specific sequence of frequencies. In FHSS systems, the spreading code is this group of frequencies to be used for the carrier signal, e.g. the hopping sequence. The amount of time spent on each hop is known as dwell time and is typically in the range of 100ms.

- Process 2 - Message modulation

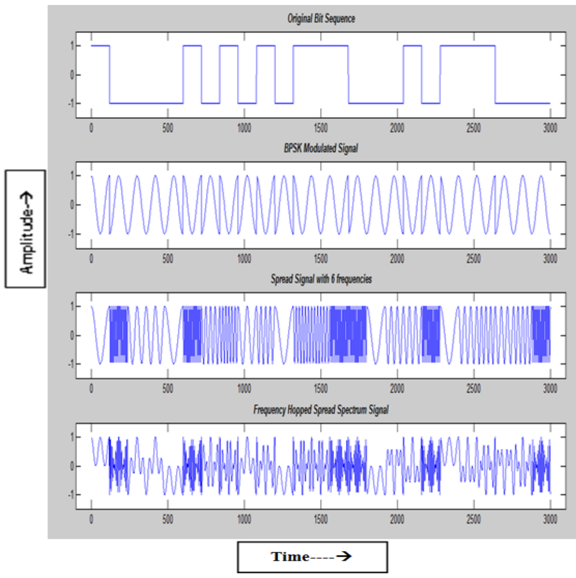
The message modulates the carrier signal, thus generating a narrow band signal for the duration of each dwell, but generating a wide band signal, if the process is regarded over periods of time in the range of seconds.

- Redundancy is achieved through the possibility to execute re-transmissions on different carrier frequencies (hops).

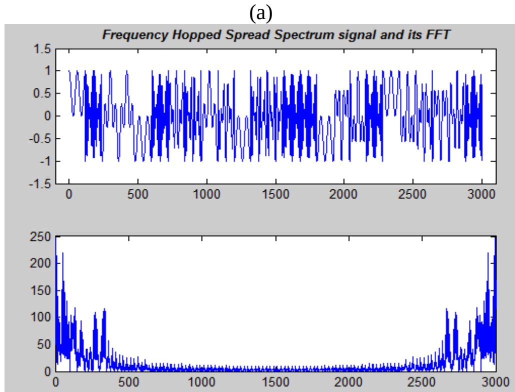
IV. Experimental Results

Fig. 8(a) shows the generation of frequency hopped spread spectrum system using BPSK modulator. Random frequency hops to form a spread signal. BPSK Signal is spreading into wider band with more frequencies. Then this signal can be expressed the FFTs to know about the frequency content of the signal (from Fig. 8(b)). FSK modulation technique can be used for performing FHSS modulation (Fig. 8(c) and Fig. 8(d)).

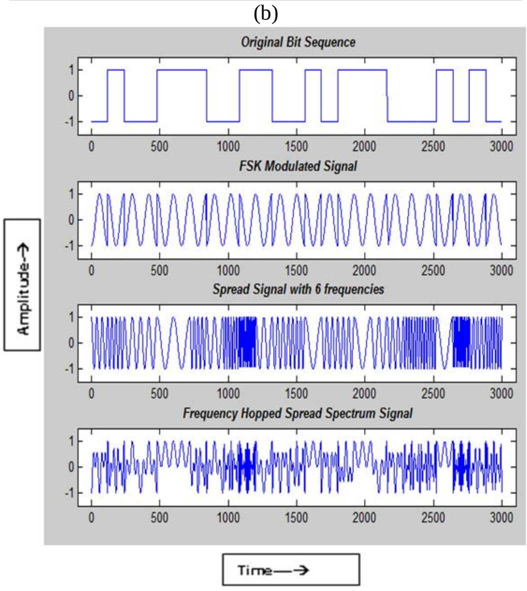
In a frequency-hopping spread spectrum sequence, each value in the pseudo random sequence is known as a channel number and the inverse of its period as the hop rate.



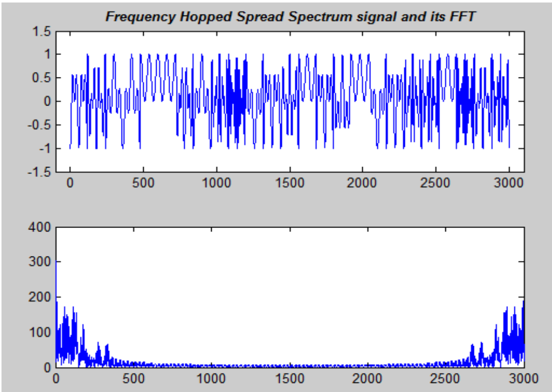
(a)



(b)

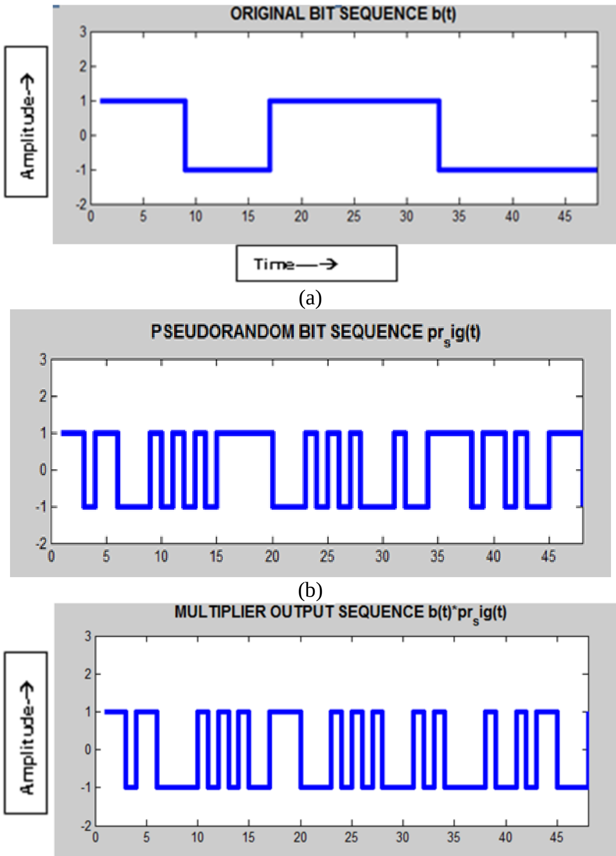


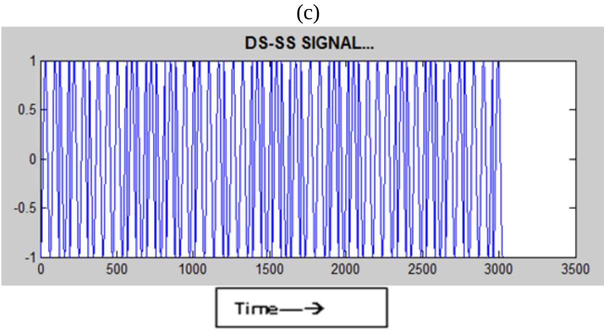
(c)



(d)

Figure 8. Implementation of frequency hopped spread spectrum





(d)

Figure 9. Simple DSSS technique

Fig. 9(a) shows the original bit sequence means the message bit. Now the pseudorandom bit sequence can be generated (from Fig. 9(b)), for performing DSSS modulation. Multiplier output sequence can be obtained from the multiplication of message bit and pseudorandom bit sequence (from Fig. 9(c)). Fig. 9(d) shows the direct sequence spread spectrum modulated signals.

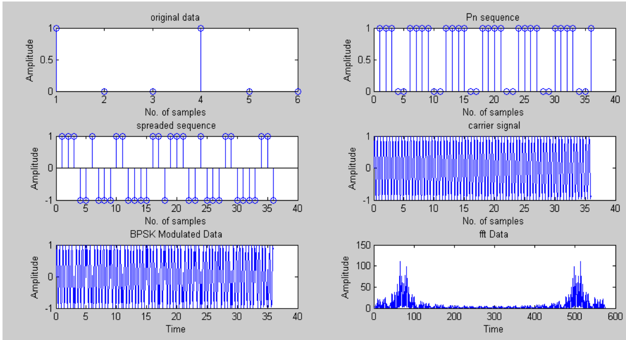


Figure 10. Implementation of DSSS system

Fig. 10 shows the message signal (1 0 0 1 0 0).Then Pseudo random sequence is generated. In a direct-sequence spread spectrum system, each bit in the pseudorandom binary sequence is known as a chip and the inverse of its period as chip rate. Then the spreader sequence is showed. By using the carrier signal for modulation, BPSK modulation with direct sequence spread spectrum is obtained. Then this output performs the fast Fourier transform.

The carrier of the direct-sequence radio stays at a fixed frequency. Narrowband information is spread out into a much larger bandwidth by using a pseudo-random chip sequence. In DSSS designs, balance modulation can be used in any suppressed carrier system used to generate the transmitted signal. Balanced modulation helps to hide the signal, as well as there is no power wasted in transmitting a carrier.

Table I shows the basic comparison between FHSS and DSSS considering the factors System collocations, Noise and Interference Immunity, Near or Far problem Throughput, Multipath Immunity, Security, Bluetooth Interference.

V. CONCLUSION

In modern communication systems the secure transmission of information is one of the prime objectives, which refers to the transfer of data such as confidential or proprietary information over a secure channel. In Spread Spectrum systems, the use of spreading sequence possess the advantage of security by its randomness and the use of the spreading sequence multiplier is done at both transmission and reception. Retrieving of the signal on the receiver side is possible, if and only if the receiver knows the spreading sequence, its compliment and the use of code bits. In case of CDMA technology, Spread spectrum technology is widely used. But normally additive white Gaussian noise can be added during the modulation process. It should be careful that noise less affects the FHSS and DSSS system.

TABLE I. COMPARISONS BETWEEN FHSS & DSSS

Systems Behaviors	FHSS	DSSS
System collocations	It is easier to use FHSS for installations of big coverage and multiple collocated cells.	DSSS can be used but collocated cells must be non-overlapping cells at the radio level which is required using directional antennas.
Noise and Interference Immunity	FHSS systems operate with SNR of about 1s8 dB	DSSS systems operate with SNR 12 dB because Phase-shift keying is used.
Near or Far problem	If the receiver uses FHSS, the worst case will be foreign transmitter, which will block some hops.	In DSSS systems, the problem is more critical and signals generated by the foreign transmitter could not be heard at the receiver.
Throughput	FHSS systems never collide. They provide more or less the same throughput as DSSS systems.	DSSS systems provide greater throughput than with non-synchronized FHSS.
Multipath Immunity	An FHSS system shows more resistance to multipath immunity.	For long distance systems, the use of directional antennas may help reducing the multipath sensitivity in DSSS systems.
Security	In FHSS, frequencies may be selected by the user and there is no need for application level encryption.	DSSS systems use spreading sequence of 11 chips, which modulate 14 channels and it needs message encryption at the application layer.
Bluetooth Interference	Bluetooth radio is a FHSS operating in the 2.4 GHz band.	DSSS is more sensitive to Bluetooth interference rather than in the FHSS systems

REFERENCES

[1] W. Stallings, *Data and Computer Communications*, Pearson Education India, Sep. 1, 2007.

[2] R. L. Pickholtz, D. L. Schilling, and L. B. Milstein, "Theory of spread-spectrum communication-a tutorial," *IEEE Trans. Communication*, vol. 30, pp. 855-884, 1982.

[3] S. Y. Tang, P. Muller, and H. Sharif, *WiMAX Security and Quality of Service: An End-to-End Perspective*, John Wiley & Sons Ltd, 2011.

[4] A. Chehri, P. Fortier, and P. M. Tardif, "A comparison between different FHSS techniques for use in a multiple access secure wireless sensor network" in *Proc. IEEE Annual Wireless and Microwave Technology Conference*, 2006, pp. 1-4.

[5] R. A. Scholtz, "The spread-spectrum concept," *IEEE Trans. Commun.*, vol. 25, pp. 748-755, 1977.

[6] M. K. Simon, J. K. Omura, R. A. Scholtz and B. K. Levitt, *Spread Spectrum Communications Handbook*, New York: Tata McGraw-Hill, 1994.

[7] R. L. Peterson, R. E. Ziemer, and D. E. Borth, *Introduction to Spread Spectrum Communications*, 1st ed. Englewood Cliffs, NJ: Prentice Hall, 1995.

[8] R. A. Scholtz, "The origins of spread-spectrum communications," *IEEE Transactions on Communications*, vol. 30, no. 5, pp. 822-854, 1982.

[9] R. A. Scholtz, "Notes on spread-spectrum history," *IEEE Transactions on Communications*, vol. 31, no. 1, pp. 82-84, 1983.

[10] R. Price, "Further notes and anecdotes on spread-spectrum origins," *IEEE Transactions on Communications*, vol. 31, no. 1, pp. 85-97, 1983.

[11] Z. Wei and X. L. Zhang, "Design of baseband signal processing in TT&C system and hardware realization based on DSSS/FHSS technique," in *Proc. International Conference on Intelligent System Design and Engineering Application*, 2010, pp. 560-564

[12] S. Ananthi, R. Hariprakash, V. Vidya Devi, and K. Padmanabhan, "Spread spectrum communication using wavelets of signal for more security," in *Proc. Advanced International Conference on Telecommunications and International Conference on Internet and Web Applications and Services*, 2006, pp. 87.

[13] H. Lehpamer, *Transmission Systems Design Handbook for Wireless Networks*, Artech House, Jan. 1, 2002.

[14] D. Torrieri, "Principles of spread-spectrum communication systems," *Springer Science & Business Media*, Jan. 16, 2006.

[15] R. E. Ziemer, *Fundamentals of Spread Spectrum Modulation*, Morgan & Claypool Publishers, 2007.

[16] O. Berg, *Spread Spectrum in Mobile Communication*, IET, 1998.

Md. Mehedi Hasan is currently pursuing B.Sc. degree program in Electronics and Communication Engineering in Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. He has a journal and conference paper. His research interest includes antenna design, machine learning, pattern recognition, neural networks, computer networking, VLSI system design, image processing, embedded system design, web security & application, telecommunication and feature selection.

Prajoy Podder is currently pursuing B.Sc. degree program in Electronics and Communication Engineering in Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. His research interest includes antenna design, machine learning, pattern recognition, neural networks, computer networking, VLSI system design, image processing, embedded system design, web security & application, telecommunication and feature selection.

Jag Mohan Thakur is currently pursuing B.Sc. degree program in Electronics and Communication Engineering in Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. His research interest includes antenna design, machine learning, pattern recognition, neural networks, computer networking, VLSI system design, image processing, embedded system design, web security & application, telecommunication and feature selection.