BER Performance Analysis of Frequency-Hopping and Direct-Sequencing Spread Spectrum for Cognitive Radio Networks

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Abstract— Cognitive radio is an encouraging technology for future wireless communication networks. Due to the rapid increase in wireless services, the RF spectrum is going through a scarcity problem. This has forced mobile operators to participate in multi-million dollar auctions to reserve some spectrum resources. Cognitive radio tries to solve this scarcity problem by effectively using the unused portions of the spectrum. FHSS and DSSS are two spread spectrum technologies used for cognitive radios. In this paper, both techniques have been discussed extensively. DSSS accesses spectrum in a sequence whereas FHSS accesses spectrum by a hopping sequence and thus provide immunity to interference and jamming signals. Also, they have been concatenated to cognitive radio and analyzed to find which spread spectrum technology provides better communication. Simulations have been performed in MATLAB environment and results are shown in the form of number of error bits (BER) generated for a range of SNR values.

Keywords- *Cognitive radio networks, spectrum sensing, spread spectrum, frequency hopping, direct sequence, DSSS, FHSS, spreading code, BER.*

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I. Introduction

A process is said to be cognitive if it involves some intellectual activity such as thinking, reasoning or remembering. So, if a wireless communication medium such as radio has these features, it is known as a cognitive radio. Thus, a cognitive radio is an intelligent radio device which can think, understand, learn and remember features of its radio environment and use them to its benefit. The term 'Cognitive Radio' was first coined by Joseph Mitola in 1998 in his dissertation work [1]. Since then, it has received global spotlight from researchers all over the world.

The electromagnetic spectrum is a limited resource of energy which is used by radio stations to transmit radio waves. The control and management of spectrum is undertaken by government authorities such as TRAI (Telecom Regulatory Authority of India) in India and FCC (Federal Communications Committee) in USA. As per a report by FCC, about 15-85% of the spectrum is not utilized at a particular moment [2]. With spectrum being a limited resource, getting the most out of it has been a challenge for these authorities. Cognitive radio is one such method introduced to tackle the problem of underutilization of spectrum. A cognitive radio intelligently changes its signal's parameter values (such as amplitude, phase, modulation etc.) to use the unused portion of the spectrum. A network of such radios is thus known as cognitive radio network.

Cognitive radio networks have two kinds of users: primary or licensed users (PU) and secondary or unlicensed or cognitive users (SU). Primary users are those which have a license from a spectrum regulatory body such as FCC or TRAI to use a particular portion of the spectrum. Whereas secondary users are those which do not have a license but they are looking for opportunities to use the spectrum. These opportunities come in the form of unused portion of spectrum, also known as white spaces. When a primary user is not using its licensed portion of spectrum, it becomes a white space for the secondary user and can be used to transmit its messages.

Industrial wireless communications systems use either fixed-frequency channels or a spread spectrum radio band. Fixed-frequency uses a single frequency channel and is the easiest to implement for both transmitter's and receiver's perspective [3]. The information signal is placed on the carrier signal using a signal modulation technique. The receiver must simply tune-in to the correct frequency to receive the signal. The received signal is then demodulated to obtain the original information signal. Such a transmitted signal is clearly on thin ice as it can be easily detected and read by anyone with a frequency analyzer. Spread spectrum systems use multiple channels within a continuous band. The frequency is automatically changed, or transmissions use multiple frequencies at the same time to transmit data [9]. In this way, techniques such as DSSS and FHSS spread the original signal over a much wider range of channels and avoid the signal being intercepted. Moreover, the signal simply appears as a background noise to a narrowband receiver and thus also evade narrowband interference.

Spread spectrum was primarily developed for military use because it uses wideband signals that are difficult to detect and have higher resistance to jammers [4]. In recent years, researchers have diverted their efforts to applying spread spectrum techniques for commercial purposes, more specifically in wireless local area networks such as a cognitive radio network.

The remaining paper is organized as follows: Section II and III overviews DSSS and FHSS with graphical representation respectively. Section IV combines the concept of DSSS modulation with a cognitive radio network. Section V depicts the MATLAB implementation of the three models to calculate BER. Section VI discusses about Simulation and results generated, with Conclusion remarks in Section VII.

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II. Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum is one of the signal modulation schemes in which the information signal is combined with a spreading signal having much wider bandwidth. In this way, the transmitted signal takes up more bandwidth than the information signal.

In direct sequence spread spectrum, the original information signal to be transmitted is divided into smaller parts; each part is allocated to a frequency channel across the spectrum. A data signal at the point of transmission is combined with a pseudo noise (PN) bit sequence (also known as a spreading code) that divides the data according to a spreading ratio [5]. These PN code symbols are known as 'chips', where each chip has a much shorter duration than an information bit. Therefore, the chip rate is much greater than the original information bit rate. The sequence of chips forms the PN sequence which is already known to the receiver. This helps the receiver to regain the original information signal.

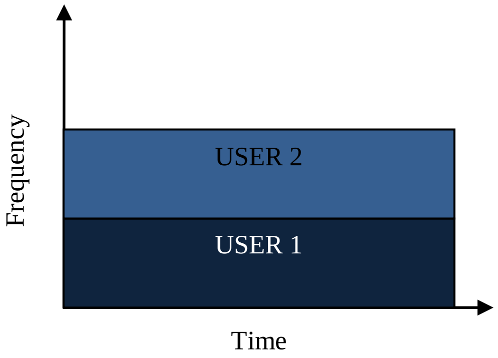

Fig.1. DSSS channel selection

The benefit of using DSSS is that the transmitted wideband signal appears as a noise signal to an interceptor and avoids intentional or unintentional interference.

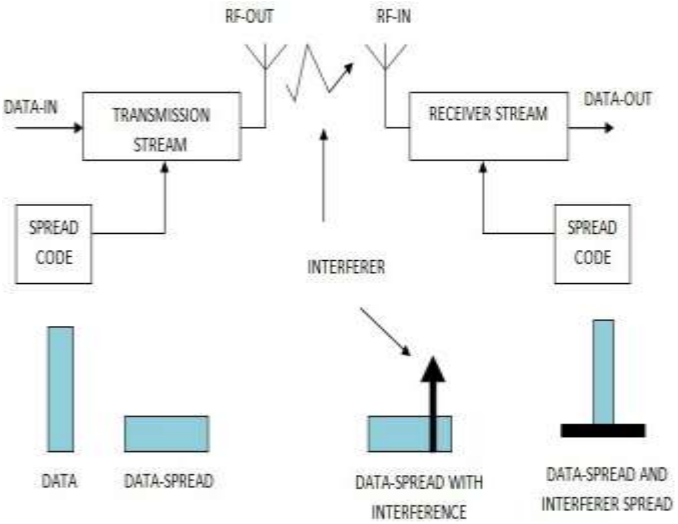

Fig.2. DSSS transmission mechanism

III. Frequency-Hopping Spread Spectrum

FHSS is another signal modulation technique to facilitate spread spectrum signal transmission. Unlike DSSS, a FHSS signal doesn't stay at one place i.e. it does not require continuous frequency channels. The frequency-hopped signal keeps on hopping from one channel to the other in a pseudorandom fashion. This is done by using a pseudorandom code which is exchanged between the two ends prior to any communication. Without this sequence, the receiver cannot rearrange the message into a meaningful format.

FHSS usually skips the frequency spectrums to mitigate the effects of interference. FHSS signal simply appears as an increase in background noise [6]. FHSS can save the energy by not transmitting on the frequency channels with interference, which usually consumes a significant amount of energy.

Apart from the advantages of DSSS, FHSS performs better in jamming scenarios. Jammers usually block a particular small range of frequencies. Thus, there is higher probability that frequency-hopped signal evades jamming more effectively than a direct-sequenced signal.

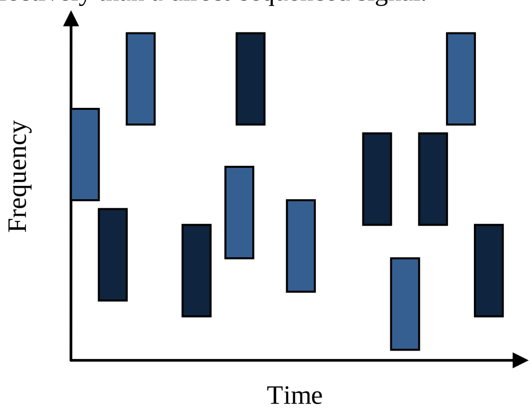

Fig.2. FHSS channel selection.

IV. DSSS With Cognitive Radio (DSSS-OB)

DSSS can be concatenated with a simple cognitive radio network where the sender and receiver are cognitive users. This means that both sender and receiver have a cognitive radio sensor attached to them which helps them to learn and transform according to their RF environment.

A cognitive radio works in four steps in a loop: firstly, the sensor performs spectrum sensing to detect spectrum holes on which it can transmit the data. Spectrum sensing techniques are used to check the availability of such frequency channels. Secondly, best available channel is selected which can handle the data to be transmitted. Thirdly, the cognitive radio accommodates multiple users to share the channels among them. This can only be done by ensuring that the signals from those users do not interfere with each other. Finally, transmission between two ends takes place till the channel is free. When the channel is required by its licensed user, the cognitive user has to vacate it and return to the initial step. In [7], a one-bit cooperative sensing based algorithm is presented. Building on that, a one-bit query-reply based cooperative sensing technique is used in DSSS-OB model. For every one-bit sensing request, a one-bit detection result is replied to the cognitive user, indicating whether to transmit data or not.

DSSS-OB has been implemented by using the above stated spectrum sensing technique, which helps in finding a set of available frequency channels on which data can be transmitted. Once the set of frequencies is generated, the conventional DSSS modulation can be performed on the data set and it can be transmitted to the other end.

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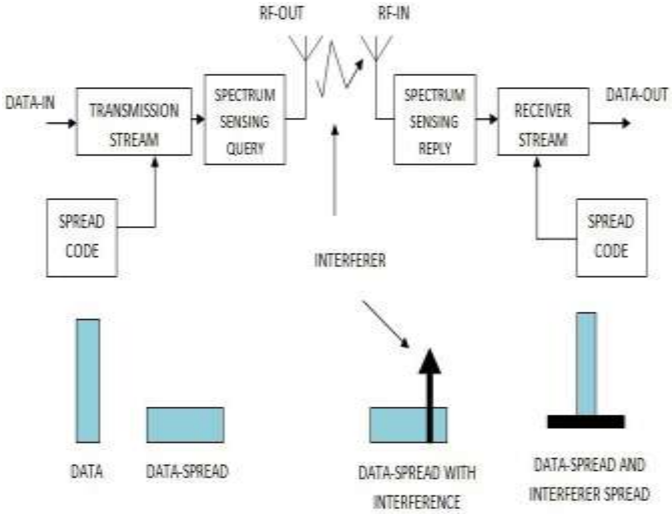

Fig.4. DSSS transmission including Spectrum sensing

V. MATLAB IMPLEMENTATION

MATLAB simulation environment has been used to implement basic models for communication between two ends using three different signal modulation techniques: DSSS, FHSS and DSSS with cognitive radio. Data is sent from one end to the other in each case and bit-error ratio (BER) for each is calculated.

During data transmission, some bits get altered in the communication channel due to noise, interference, or bit synchronization errors. BER gives the ratio of number of error bits to the total number of bits transmitted during a time interval [8]. In this paper, BER has been calculated for a range of SNR values in each of the above cases using MATLAB simulations.

A general algorithm for FH/DS propagation of data for the three models is discussed below;

At sender's end:

1. Random bit pattern D(b) is generated to simulate the input signal.
2. Carrier frequencies Cf(n) are generated using sine and cosine signals.
3. Multiplication of carrier frequency with input signal DCf(b) to form spread signal.
4. Division of spread signal into 'n' smaller parts $\int_1^n DCf(n)$.
5. Sequencing the different parts according to the required DS or FH modulation.
6. Transmission over an AWGN channel.

At receiver's end:

1. Reception of the transmitted signal at the other end.
2. De-sequencing the different parts according to the previously known code.
3. Concatenation of parts to obtain one single signal.

$$DCf(b) = \int_1^n DCf(n)$$

4. De-spreading the code using sine and cosine signals to obtain the original signal.

$$D(b) = DCf(b)-Cf(n)$$

The algorithm for spectrum sensing in case of direct sequencing is discussed below;

1. Cognitive/Secondary user (SU) sends a one-bit request to other 'n' SUs in its network.
2. Each SU performs spectrum sensing to detect PU.
3. Detection results are returned as 'n' one-bit replies to the requesting user.

Based on these, the cognitive user transmits the data by avoiding interference.

VI. SIMULATION AND RESULTS

Simulation results show that FHSS has a lower BER than conventional DSSS, more specifically at lower SNR values (<12dB). But, DSSS-OB performs much efficiently than both DSSS and FHSS as evident from the graph shown below. DSSS has almost a linear decrease in BER with an increase in SNR whereas FHSS shows irregularity in maintaining BER (but still lower error bits).

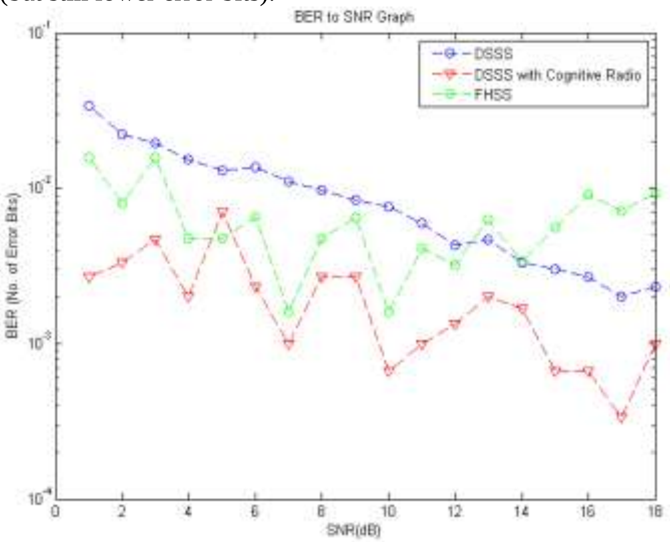

Fig.3. BER versus SNR graph

The following table below shows the specific BER value calculated at each SNR level, taken from 1 to 18 (in decibels).

SNR Levels (dB)	DSSS	FHSS	DSSS-OB
1	0.0330	0.0095	0.0067
2	0.0237	0.0127	0.0030
3	0.0253	0.0079	0.0017
4	0.0157	0.0048	0.0040
5	0.0147	0.0063	0.0050
6	0.0143	0.0016	0.0013
7	0.0100	0.0032	0.0023
8	0.0070	0.0091	0.0013
9	0.0063	0.0073	0.0013
10	0.0067	0.0032	0.0040
11	0.0053	0.0072	0.0007
12	0.0063	0.0096	0.0017

13	0.0033	0.0014	0.0010
14	0.0050	0.0053	0.0010
15	0.0027	0.0091	0.0013
16	0.0023	0.0011	0.0003
17	0.0023	0.0096	0.0003
18	0.0033	0.0041	0.0007

Table.1. Calculated BER for each SNR

From the table below, it can be observed that the average BER in case of conventional DSSS is almost five times the average BER in DSSS with spectrum sensing. Clearly, there is a drastic decrease in number of error bits in DSSS-OB.

	DSSS	**FHSS**	**DSSS-OB**
Total BER	0.187333	0.112904	0.037666
Average BER	0.010407	0.006272	0.002093

Table.2. Total and Average BER for all models

VII. CONCLUSION

Cognitive radio is thought of as the technology of the future radio-based communications, but its need in the telecom sector cannot be felt more today. Regulatory authorities are auctioning portions of spectrum to telecom organizations for unlicensed band usage. Millions of dollars are being spent on such auctions to acquire just a small portion of spectrum. Cognitive radio can help boost spectrum utilization by optimally using such unlicensed bands. This paper studies the effects on BER when a cognitive process is embedded with a signal modulation technique, such as DSSS. Further research in this field will be carried out in future to study the effects on BER with FHSS modulation.

REFERENCES

[1] J. Mitola III, “Cognitive radio: Making software radios more personal” *IEEE Personal Communications*, pp. 13-18, 1999.

[2] Federal Communications Commission (FCC), “Spectrum policy task force”, *ET Docket No.2*, pp. 1-135, 2002.

[3] [Online] www.wilsonmohr.com/wireless.nsf/Content/wirelessresources

[4] H.H.Chen,“The next generation CDMA technologies”, *John Wiley & Sons*, 2007.

[5] W. Xiaoying, "Study spread spectrum in Matlab", In *School of Electrical and Electronics Engineering, NTU, Singapore, Congress*, 2003.

[6] R. D. Raut, K. D. Kulat. “BER performance maintenance at high data rates in cognitive radio.” *IEEE*, pp. 62-67, 2010.

[7] N. Zhao, F. R. Yu, H. Sun, and A. Nallanathan, "Energy-efficient cooperative spectrum sensing schemes for cognitive radio networks", *EURASIP Journal on Wireless Communications and Networking*, Vol. 1, pp. 1-13, 2013.

[8] R. Hranac,"BER and MER fundamentals", *CISCO, San Francisco*, CA, USA, 2007.

[9] D.R. Kaufman,"Industrial Wireless Technology and Planning", *Instrumentation Reference Book*, 2010.