Abstract—This paper discusses the Frequency Hopped Spread Spectrum (FHSS) communication using chaos. The spread spectrum technique of frequency hopping uses pseudorandom number (PN) generator to produce a random sequence of frequencies. In multiple access applications, it is desirable to employ sets of frequency hopping sequences that have good Hamming correlation properties, large period and also large linear span. Most algebraic designs for frequency hopping sequences are based either on PN sequences or else on Reed-Solomon (RS) codes. These sequences having short linear span are potentially weak when the threat of intelligent jamming exists. A new class of signature sequences for use in Frequency Hopped Spread Spectrum communication systems is proposed. In arriving at these sequences, the theory of chaos has been used. The correlation properties of these chaotic sequences are similar to random white noise. The numbers and lengths of chaotic sequences are not restricted like m sequences. The performances of chaotic sequences in multiple access communication are shown to be similar to that of PN sequences. Furthermore, due to their noise like appearance, chaotic sequences outperform PN sequences in low probability of intercept. In this method the spreading sequences change from one bit to the next in very random like fashion, causing undesired interception to be very difficult.

Keywords—FHSS, chaotic system, chaotic sequences, PN sequences.

I. INTRODUCTION

A Chaotic System is a dynamic system which shows complex behaviour. One of the defining attributes of a chaotic system is the dependence on initial Conditions. Time series generated from chaotic systems are wideband in nature and noise like in appearance. Because of these special properties, chaotic systems are being widely studied for secure communications applications for encryption and decryption of messages. Encryption of messages is the most common method used for secure communication of sensitive information. However, this requires that an authorized receiver knows the “key” used by the sender to encrypt the message. In classical cryptic communications, this key, which is typically a sequence of numbers, is usually sent over a secure channel while the encrypted messages are transmitted over a public channel. It would be, of course very useful if the key is not transmitted, but generated at the receiver end [2].

The secure message communication has been used in satellite communications for TV broadcasting, telephony and bundled data tracking, military communication, data relay for space missions, and other point to point communication. Chaotic communications based on the transmission of messages encoded using a chaotic waveform are currently a subject of great interest, attracting increasingly more research activities compared to conventional secure communication systems. There are several unique features of chaotic communication systems. Potential benefits of Chaotic communications includes the efficient use of bandwidth of a communication channel, utilization of the intrinsic non-linearities in communication devices, large signal modulation for efficient use of carrier power, reduced number of components in a system, and above all, message security by chaotic encryption [1],[2].

The chaotic sequences are generated using discrete, chaotic maps. The sequences even though generated by completely deterministic means, have characteristics similar to those of random noise. Surprisingly simple maps can generate large numbers of these noise-like sequences having low cross-correlations. The lengths of the sequences are unlimited. The noise-like feature of the chaotic sequences is very desirable in a communication system [3].

The manuscript is organized as follows. Section II describes the chaotic sequence generation and its properties. The operation of Frequency Hopped Spread Spectrum communication system using chaos sequence generator is explained in Section III. The simulation results of communication system are explained in section IV.

II. CHAOTIC SEQUENCES

The chaotic sequences are generated from logistic map. These chaotic sequences are used in FHSS instead of PN sequences to improve the security of communication system.

A. Need of Chaotic Sequences in FHSS

In order to spread the bandwidth of the transmitting signals, binary pseudorandom noise (PN) sequences have been used extensively in spread spectrum communication systems.
But PN sequence is not completely random with the sequence is repeating over a period [6]. The PN sequence is usually generated using sequential logic circuit; if a linear shift register enter into all zero state it will not come out of it. Also the maximum length of the code is $2^m-1$. The maximal-length linear code sequences (m-sequences) have very desirable autocorrelation functions [7]. However, large spikes can be found in their cross-correlation functions, especially when partially correlated, as in the case of multipath environments. Another limiting property of m-sequences is that they are relatively small in number.

The property of chaotic sequences that are generated is similar to that of pseudo-noise sequence. The chaotic sequence generates large length of codes which shows good randomness. The random nature produces high security than PN sequences.

B. Generation of Chaotic Sequences

The chaotic sequences are generated by following steps

- Chaotic signal generated from logistic map
- Sample and hold
- Encoding

The Fig.1 shows how the chaotic sequences generated from chaotic signal.

A chaotic dynamic system can be represented by difference equation using logistic map as [3]

$$X_{n+1} = rX_n(1 - X_n)$$

Where, $1 < r \leq 4$, and $r$ is called the bifurcation parameter. Depending on the value of $r$, the dynamics of this system can change dramatically, exhibiting periodicity or chaos. For $3.57 < r \leq 4$, the sequence is, for all practical purposes, non-periodic and non-converging. Fig.2 shows the chaotic signals with different values of $r$.

![Fig. 2 Chaotic signals](image)

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### B. Generation of Chaotic Sequences

The chaotic sequences are generated by following steps

1. **Chaotic Signal Generation Using Logistic Map:** A discrete time dynamical system is defined by the state equation

   $$X_{k+1} = f(X_k) \quad 0 < k < 1 \quad k=0,1,2,......$$

   where, $X_k \in \mathbb{R}$ is called the state, and $f$ maps the state $X_k$, to the next state $X_{k+1}$. Starting with an initial condition $X_0$, repeated applications of map $f$ give rise to sequence of points $\{X_k; k = 0, 1, 2, ...\}$ called an orbit of the discrete-time system.

2. **Sample and Hold:** Sample and hold step is used when multiple samples are to be measured at the same time. Each value is sampled and held, using a common sample clock. The chaotic signal generated from logistic map is sampled and held.

3. **Encoding:** Encoding is the process of transforming information from one format into another. Here the amplitude of signal is converted into digital sequences by using two levels of zeros and ones.

### C. Properties of Chaotic Sequences

The property of chaotic sequences that are generated is similar to that of pseudo-noise sequences. Its autocorrelation value is very low between shifted versions of the sequence and cross correlation values are very low between any two sequences [4],[5].
The autocorrelation and cross correlation functions are shown in Fig. 3. The autocorrelation properties of the chaotic sequences look very much like random noise. Their cross correlation functions are very similar except the peak at zero lag in the autocorrelation. If the auto correlation value is less, then synchronization is perfect in the receiver side. The low crosscorrelation value indicates that interference due to other channel is less.

III. FHSS COMMUNICATION SYSTEM USING CHAOTIC SEQUENCE GENERATOR

The FHSS communication system consists of transmitter and receiver section [7]. Here the operation of both transmitter and receiver operation explained in below.

A. Transmitter section

The transmitter section is similar to FHSS with PN sequence generator. Here instead of PN sequence generator chaotic sequence generator is used. The transmitter section of FHSS with chaos sequence generator is shown in Fig.4.

The input binary data sequence is applied to the BPSK modulator. The phase of the modulator output signal changes based on the input symbol. If input is zero, there will be no change in phase; else 180 degree out of phase with the carrier signal. The output of BPSK modulator is then applied to the mixer. The other input to the mixer is particular frequency from frequency synthesizer. The frequency selection in frequency synthesizer is based on the code generated from chaos sequence generator. The output of frequency synthesizer at particular instant is the frequency slot or hop which is mixed with BPSK signal. The mixer output is sum of frequency component of BPSK and frequency hop from synthesizer. This signal is the frequency hopping signal which is transmitted over the channel.

B. Receiver Section

In receiver, the inverse operation of the transmitter has to be carried out. Assume that both transmitter and receiver are synchronized. The receiver section of FHSS with chaos sequence generator is shown in Fig.5.

In the correlator receiver the signal is applied to the multiplier where the signal is multiplied with the local carrier signal and passed on to the integrator. The combination of both multiplier and integrator is called as correlator. The correlator output is given to the decision device where comparison is done. The comparator output will be zero when the correlator output is less than zero and one when the comparator output is greater than zero. Thus the binary data get it from the comparator.
IV. SIMULATION RESULTS

The simulation is done using MATLAB code. First chaotic signal is simulated using difference equation. Here logistic map is used to generate this difference equation. These equations are dependent on initial conditions; even small change in this initial value brings about drastic changes in output. The system generates the future value based on these initial values. The difference equation used for this simulation is

\[ X_{n+1} = r X_n (1 - X_n) , \quad n=1,2, \ldots \]

Where, \( X_1 = .5 \) and \( r = 3.789 \) are assumed value for generating the signal or samples.

These sample values are rounded off to near values nearer to either is zero or one. Then we get the sequence having zeros and ones. This sequence is used for selection of frequencies in frequency synthesizer. Fig.6 shows the chaotic signal and its sampled value. The last row has the rounded off values.

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The encoded values of chaos signals are used for chaotic sequences in chaos sequence generator. The length of the sequence is chosen as per requirement. There is no restriction in length of the sequence and the sequences are also random in nature.

The input binary data sequence is applied to the BPSK modulator. The phase of the modulator output signal changes based on the input symbol. If input is zero, there will be no change in phase; else 180 degree out of phase with the carrier signal. This is shown in Fig.7..

![Fig. 6 Chaos sequence generator waveforms](image)

The hop generated for each bit is shown in fig.8. These hops are generated from frequency synthesizer. The inputs of the frequency synthesizer are controlled by chaos sequence generator. Three successive bits from chaos sequence generator is used to control the frequency hops generated by synthesizer. The bits of chaos sequence generator changes randomly. Therefore the frequency hops generated also changes randomly. Thus, there is no repetition like PN sequence generator. The frequency hopping signal is like a noise signal [8].

![Fig. 7 BPSK modulated waveform](image)

![Fig. 8 Hops and frequency hopping signal](image)
In the receiver, the received signal is dehopped by the frequency synthesizer. The dehopped signal is just like BPSK modulated signal and hence the input sequence retrieved by BPSK demodulation. These two signals are shown in Fig. 9.

The output signal in Fig. 9 is same as input signal in Fig. 7. That is the bits are retrieved by the receiver is same as the input binary bits.

V. CONCLUSION

The use of chaotic sequences for FHSS system has several advantages over conventional methods. One advantage is the availability of an enormous number of different sequences of a given length as compared to the PN sequences. The generation and regeneration of chaotic sequences is very simple and involves the storage of only a few parameters and functions even for very long sequences. Moreover, the code sequences are easily made independent from one information symbol to the next. The chaotic sequences make the transmitted signal look like noise. As a result, chaotic transmissions have less risk of interception and are hard to be detected by eavesdroppers. They possess low auto and cross correlations with spectral density similar to wideband noise. Therefore this is used in multiple access communication.

REFERENCES


