A Multi-Carrier Structure for Chaos –Shift Keying

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Abstract— *The next generation of wireless communications networks needs higher data transfer rates; this requires to provide wireless communication systems operating at higher spectral efficiencies. In this research, an overall study on performing a Multi-Carrier Structure for Chaos Shift keying using the Orthogonal Frequency Division Multiplexing (OFDM) technique because of the limited speed provided by Chaos Shift Keying due to the spreading factor. OFDM has become an effective investment in the available bandwidth and the basis of 4G, 5G mobile communication systems that enable high data rates in the wireless communication system. The chaotic sequence was generated by the proposed tent map. The performance test using the Bit Error Rate (BER), Mean Squared Error (MSE), correlative test, and the chaotic characteristics of the chaos generator sequence using are tested by the Lyapunov Exponent. Results showed the proposed method for tent map when (a=0.5) provide ideal chaotic sequence characteristic, in which difficulty expecting the chaotic type and initial condition. In addition, the proposed system to multi-carrier structure for the CSK system with different Spreading Factors (SF) values outperforms on a CSK system in height the data transmission rate.*

Keywords—**Chaos, Chaos Shift keying, Orthogonal Frequency Division Multiplexing, Multi-Carrier.**

I. INTRODUCTION

The increasing demand for multimedia services requires high data transmission speeds, but this condition is significantly restricted by Inter-Symbol Interference (ISI) due to the numerous paths being present. Multi-carrier modulation techniques, including modulation with OFDM, are considered as the most promising method of combating this problem [1]. In OFDM, the baseband signal cannot be transmitted without the use of modulation techniques, such as M-QAM quadrature amplitude modulation [2]. Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) algorithms are used to decode the signal to multiplex the signal together at the transmitter and receiver, respectively. In order to prevent inter-symbol interference (ISI) caused by the propagation path[3], OFDM systems implement a guard interval[4]. A primary communication system technology has been multicarrier modulation (MCM). A chaotic generator is a state-machine with infinite states, so it can generate non-repeating sequences. This non-periodic behavior of the chaotic generator presented a potential advantage in terms of protection, synchronization and device capability of a spread spectrum communication over traditional pseudo-noise-based system. Since Pecora and Carroll solved synchronization in 1990 [5]. Increasing numbers of proposed systems have been used for both analog and digital systems that use chaos theory in SS communication. These schemes include chaotic masking, chaos modulation, chaos shift keying (CSK), and chaotic CDMA sequence [6], but are not limited to them. Chaotic signals have auto-correlation functions such as impulse and a white wideband power spectra. There is also a very low value to the cross-correlation of chaotic signals [7]. The tent map does not show noise-like properties (far from a delta function) [8]. The combination of MC transmission and optical digital chaos-based modulation will solve the delay line problem perfectly [9]. In this paper, it will modification for the chaotic sequence to the tent map (when a=0.5) to be autocorrelation closer for delta function without changing the chaotic behavior (linear transformation) to generate ideal chaotic sequence (shown noise-like properties) so it appears as a noise that is difficult discern information carried by the signal, difficulty expecting the chaotic type, boost privacy, and enhancing the encryption efficiency, and introducing propose to design a multi-carrier structure for CSK system for multimedia data transmission with high spectral efficiency and a more secure.

II. LITERATURE REVIEW

In [10] the authors presented an analysis of the error rates associated with a signal with CSK modulation and sent through an IFFT/FFT OFDM transmission system where it used CSK demodulation for each DFT output and after that data stream conversion from Parallel to Serial, where it used bit error rates BER to calculate the impact of channel imperfections on the signal transmitted. Results showed MC-CSK performance under AWGN: its BER efficiency increases for the large data frame size and MC-CSK's BER output degrades with a large spread factor. In [9] the authors presented a Multi-Carrier Chaos shift keying (MC-CSK) modulation system. The new system adopts multiple subcarriers, on which all chaotic basis signals are simultaneously transmitted along with multiple data-bearing signals. The data-bearing signals and their references are separated by the channels Quadrature and In-phase while sharing the same subcarriers. In addition, the efficiency of the proposed system is further enhanced by normalizing all chaotic basis signals using the Gram – Schmidt algorithm and rendering them purely orthogonal. In addition, the MC-CSK system's bit error rates (BERs) over additive white Gaussian noise and Rayleigh multipath fading channels are obtained. Simulations are finally carried out under various channel conditions and the effects of system parameters on BER performance. Results showed MC-CSK system under AWGN is more sensitive to channel noise and high output of BER for a situation where subcarriers are small. On the other hand, an increase in subcarriers for fixed Eb / N0 means that more orthogonal basis signals are used to represent more symbols. This helps to reduce noise interference and improve MC-CSK's BER efficiency. In [7] the authors presented an extensive study on the performance of CSK system and the correlative properties of logistic map and tent map. The logistic map has auto-correlation functions such as impulse. There is also a very low value to the cross-correlation of chaotic signals (logistic map shown a noise-like properties). While tent map does not show noise-like properties (far from a delta function).

III. BACKGROUND

A. *Chaos Shift Keying (CSK)*

Where in binary chaos shift keying modulation, chaotic signals carrying different bit energies are used to transmit binary information [11] [12][13][14][15][16][17]. Transmitting one chaotic signal $g_1(t)$ or $g_0(t)$ at a time encodes an information signal. For example, if the binary information signal "1" occurs at time t, the chaos signal $g_1(t)$ is to be sent, and the chaos signal $g_0(t)$ is to be sent for information bit "0" Fig.1 depicts a block diagram of a (binary) CSK communication system. Just one chaos generator is used on the transmitter terminal, as can be observed. In such a scheme, i-th bit $\alpha_i \in \{+1, -1\}$ is represented by one chaotic sequence $g_k = \{g_{k,i}\}$ where, $k = 1,2,\cdots; i = 1,2,\cdots; g_{k,i}$ is the chaotic sample of the k-th component, with the expected value $\varepsilon(g_{k,i}) = 0$. Assume that the durations of a chaotic sample and a bit denote respectively T_c and T_b , and the global spreading factor are denoted by: $2\beta = \frac{T_b}{T_c}$. Accordingly, the i-th modulated sample output from a CSK modulator corresponding to α_i is expressed as $s = \alpha_i g_k$, where $i = 1,2,\dots,2\beta$, $g_{k,i}$ is the carrier and $s_k = [s_{k,1}, s_{k,2}, \dots, s_{k,2\beta}]$ refers to the total baseband signal transmitted during the k-th bit duration. Note that both the numbers $\mathbf{S_{k,i}}$ and $g_{k,i}$ are real. This signal is then passed through a noisy channel and detected by a coherent demodulator. Based on the received signal vector $r_k = [r_{k,1}, r_{k,2}, \dots, r_{k,2\beta}]$ representing the received CSK during the k-th transmission period (i.e., bit duration), y_i (demodulator output) is calculated using:

$$y_i = \sum_{k=2\beta(i-1)+1}^{2\beta} r_k g_k \qquad (1)$$

The decoded bit then is determined on the basis of the rule of hard-decision: $\propto_i = +1$ if $y_i \geq 0$ and $\propto_i = -1$ otherwise. The transmitted signal is given by [18]:

$$s(t) = \begin{cases} g_0(t) & \text{symbol "0" is transmitted} \\ g_1(t), & \text{symbol "1" is transmitted} \end{cases} \qquad (2)$$

Communication systems dependent on chaos can be divided into two major groups of systems: coherent and non-coherent structures[19]. The receiver has to return the chaotic carrier to output for incoherent demodulation systems, while demodulation is performed solely on the basis of the received signal in the non-coherent system[13].

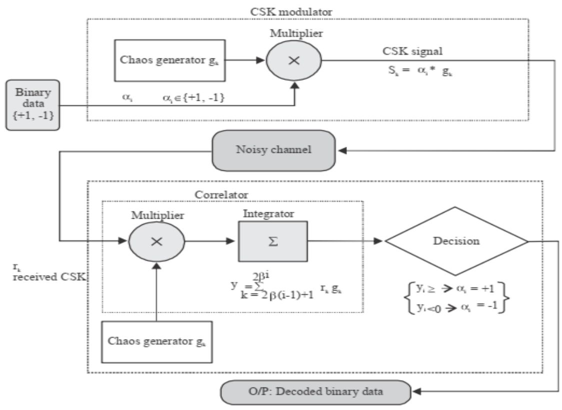

Fig1. Chaos Shift Keying (CSK) system

B. *Chaotic Maps*

A large number of different types of mathematical models have been derived in the past and explored in the theory of chaos. There have been generations of chaotic maps coming from many different directions. This can be a complex or simple control system, a mathematical equation such as a differential equation, or a basic modeling of circuits like the Chua circuit. [18].

C. Tent map:

widely used discrete chaotic map is the Tent Map. The chaotic sequence generated by the tent map was widely used in the area of chaotic spread spectrum communication, chaotic encryption scheme, chaotic optimum algorithm, and so on. Its formula is [20]

$$x_{n+1} = \begin{cases} \frac{x_n}{a} & , x_n \in [0, a) \\ \frac{1-x_n}{1-a} & , x_n \in [a, 1] \end{cases} \quad (2)$$

The tent map is piecewise linear, where the control parameter is a∈(0,1) and the vector is $x_n \in (0,1)$. When $a \neq 0.5$ and a correspond to most interval parts (0,1), good pseudo-randomness is presented by the process. [21].

D. OFDM

Chang initially proposed the OFDM system in1966 [22]. The data will originate as a stream, to be transmitted over the orthogonal carriers. After parallel transformation applied to the modulator, this serial data is the mapping of data by QAM baseband modulator, the step preceding the data arrives at IFFT stage. IFFT and FFT algorithms were used by OFDM systems at the transmitter and the receiver respectively to multiplex and relay data signals simultaneously over a range of subcarriers. In the discrete time the mathematical form of IFFT as follows [23]:

$$x_k = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} X_m e^{\frac{j2\pi km}{N}} \quad (3)$$

Where, xk is a signal represented in a discrete time domain, whereas Xm is a complex number represented in a discrete frequency field. To reduce the chance of inter-symbol interference (ISI) the Cyclic prefix (CP) is inserted. It also decreases the probability of inter-carrier interference [24].
The incoming signal in the channel will be mixed with an AWGN-type noise and the cyclic prefix will be removed at the receiver and the FFT-stage output in the discrete frequency domain as follows [25]:

$$Y(m) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y_{(n)} e^{-j2\pi km/N} + W(n) \quad (4)$$

Where Y(m) is the FFT output, W(n) is the AWGN; and(n) is the received signal after the AWGN channel is passed.

E. Mean Squared Error

The aim of the measure of signal similarity is to compare two signals by providing a quantitative score reflecting the degree of integrity between them or, on the other hand, the level of error between them. No method has received better attention than the MSE because of the clear interpretation and simple formulation that allowed this technique to become one of the most widely used methods in the field [26]. The MSE is lower-bounded at zero when the two images are close, and has no upper bound [27]; MSE greater values indicate lower image /similarity [28]. For two images and, of size N×M [27].

$$MSE(X,Y) = \frac{1}{M \times N} \sum_i \sum_j \left[x_{i,j} - y_{i,j}\right]^2 \quad (5)$$

IV. RESEARCH METHOD

The approach proposed for this study was splited into two stages. In the transmitter, the first stage includes input data, pre-processing of the data, then generating the chaotic sequence by the tent map after modifying it without changing the chaotic behaviour (linear transformation) for increasing the security level, after the performance test for the chaotic map using correlative test and the chaotic characteristics test of the chaos generator sequence by the Lyapunov Exponent. the proposed tent map be in the form of the following equation:

$$\boldsymbol{x_{n+1}} = \begin{cases} \frac{\boldsymbol{x_n}}{\boldsymbol{a}} & , \boldsymbol{x_n} \in [\boldsymbol{0}, \boldsymbol{a}) \\ \frac{\boldsymbol{1-x_n}}{\boldsymbol{1-a}} & , \boldsymbol{x_n} \in [\boldsymbol{a}, \boldsymbol{1}] \end{cases} \quad (6)$$

$$\boldsymbol{x = 2 * x - 1}$$

then modulation binary information by using CSK that is generated by chaos CDMA. The second stage includes transmission for modulation data by CSK via the MC-CSK system using OFDM technique Fig.2 illustrates the principal stages of the system proposed CSK-OFDM. MC-SCK on at the transmitter, the data is converted from serial to parallel, data are modulation by M-QAM then converted from the frequency domain to the time domain by using IFFT. A cyclic prefix (CP) is inserted into each symbol to avoid inter-symbol interference (ISI), and then converted from parallel to serial. The CSK-OFDM signal is ready for transmission. At the receiver, all stages of the transmitter will be reversed, which include analog to digital conversion, converting from serial to parallel, cyclic prefix elimination, transferring the data from the time domain to the frequency domain by using FFT, applying demodulation of QAM, and transferring from parallel to serial, CSK-demodulation, then applied the data words are taken as the same word size of the original data after the preceding operations.

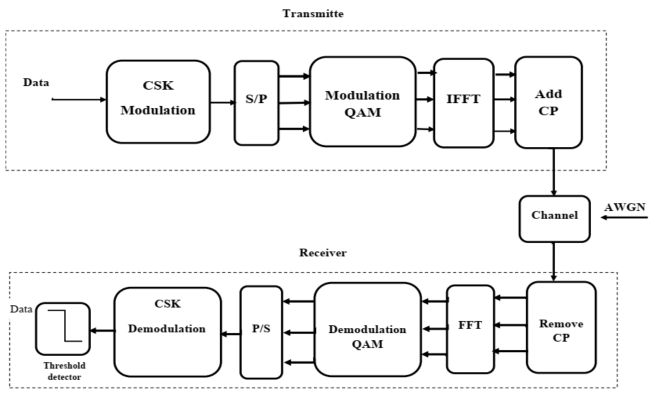

Fig. 2. Diagram of CSK-OFDM System

V. RESULTS AND DISCUSSION

A. Lyapunov Exponent:

The control parameter is *a*. When parameter α equal to 0.5, the proposed tent map will have the highest Lyapunov Exponent, where is equal to (1.3849), it exhibits chaotic behavior as illustrates in Fig.3 and Table I that shows the highest Lyapunov Exponent values for sequence chaos systems for versus parameter α, the proposed chaotic to modify tent map has the highest Lyapunov Exponent compared with tent map. Fig.4 shown Lyapunov Exponent for the tent map.

TABLE I.

Chaos map	The highest Lyapunov Exponent to chaos map for versus parameter α	
	Parameters	The highest Lyapunov exponent
Proposed tent map	0.5	1.3849
Tent map	0.5	0.6924

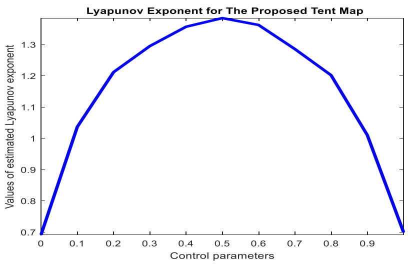

Fig. 3. Lyapunov Exponent for the Proposed Tent Map

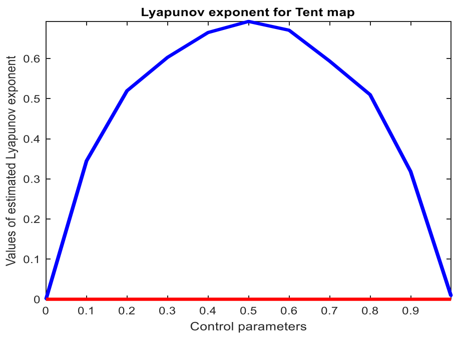

Fig. 4. Lyapunov Exponent for Tent Map

B. Autocorrelation test:

Autocorrelation test is a measure of the efficiency of the generators used in this research and therefore it is useful to choose the best generator for encryption. It is easy to see that the autocorrelation for the proposed tent map has reached an ideal state when the control parameter is (α=0.5) i.e. The autocorrelation is like and closest for delta function as illustrates in TableII and Fig.5. Therefore, the mean square error between the delta function and autocorrelation of the proposed tent map gives a lower difference compare with the tent map. Fig.6 shown autocorrelation for the tent map.

TABLE II.

Chaos map	The mean square error between autocorrelation for chaotic map with Delta function		
	Parameters	*Data length*	*MSE*
Proposed tent map	0.5	1000	47.7417
Tent map	0.5	1000	21141

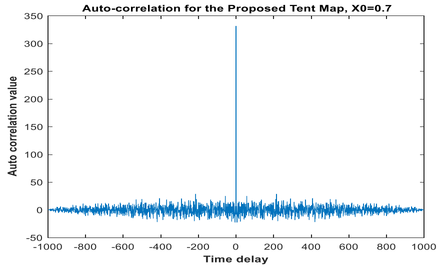

Fig. 5. Autocorrelation for the Proposed tent map

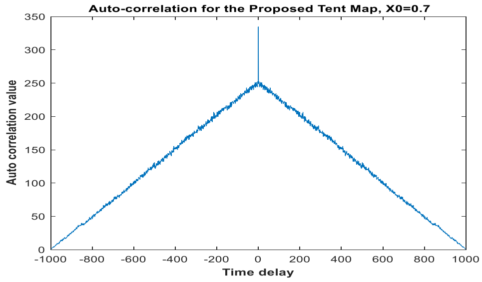

Fig. 6. Autocorrelation for the tent map

C. Simulation of CSK-OFDM and CSK System:

It is seen the BER performance of CSK-OFDM with different spreading factors. The CSK-OFDM system when a number of sub-carriers (FFT) are equal (8) has BER performs better than when number of sub-carriers are equal (16). But FFT=16 better than FFT=8 in increased data rate. A comparison between both systems performance CSK-OFDM system and the CSK system can be stated when SF=5 and SF=10. First, it is noticed that the CSK-OFDM system with different spreading factors outperforms CSK in improving data rate, but at the expense of more error (BER). Second, increasing SF will improve bit error rate in both CSK and CSK-OFDM resulting in a decrease in the effective signal noise it was sent out, but decreases data rate as shown in Fig [7-9].

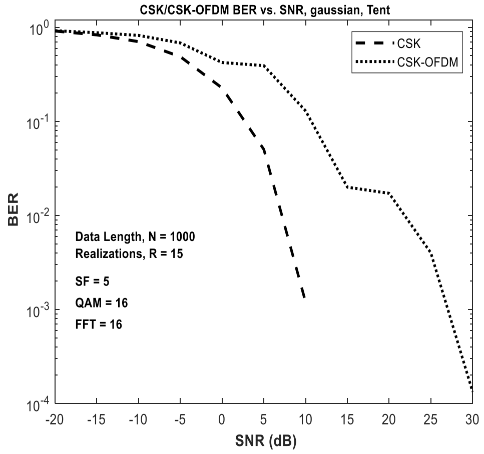

Fig. 7. BER performance CSK and CSK-OFDM, 16-QAM, FFT=16, SF=5

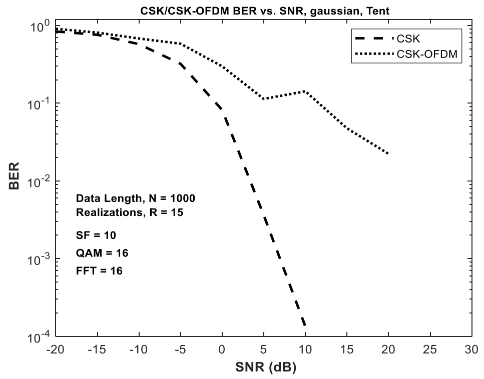

Fig. 8. BER performance CSK and CSK-OFDM, 16-QAM, FFT=16, SF=10

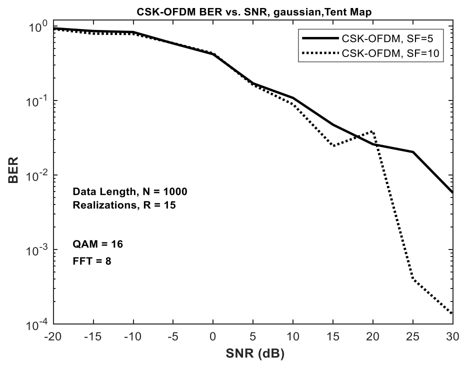

Fig. 9. BER performance CSK-OFDM, 16-QAM, FFT=8

D. Similarity Measures for Image

In the simulation, similarity methods are applied to compute the similarity between images (original and version received) over the CSK-OFDM system as shows in Fig. 10. MSE is a measure for an index of image quality, and a statistical similarity. Fig. 11 shows MSE performance on SNR -20:30 and 15 Realizations to image transmission over the CSK-OFDM system. an SNR value affects the transmitted signal, the low value of SNR e.g. when image transmission over the CSK-OFDM system (SF=10, FFT=8, 4-QAM) the value is within the range of [-20 -30], when the SNR value 10 or more, the value of the similarity ratio is very high (the MSE is lower-bounded at zero).

Fig. 10. Received image with SNR =10in dB

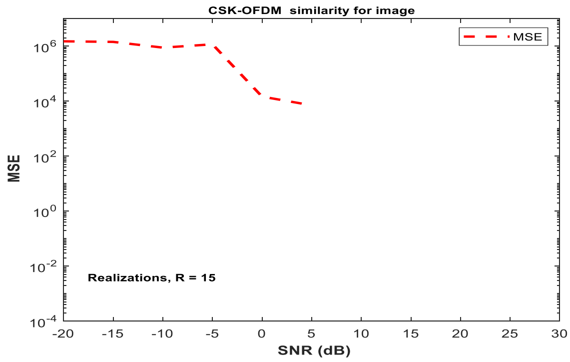

Fig. 11. MSE Performance to image transmission over the CSK-OFDM with Fifteen Realizations and SNR range -20:30 dB

VI. CONCLUSION

The performance of the Multi-Carrier structure for CSK studied by using OFDM for under AWGN noise with different values of spreading factor (SF). It is concluded the chaos resulting in the proposed tent map is very sensitive to the initial condition, difficulty expecting the chaotic type and initial condition, this property is very important to communications security that prevents attackers from predicting value or altering the signal. It is fulfilling the concept of a secure chaotic system; therefore, this chaos is applied in digital communication and multimedia security. And also, the proposed system to the structure for CSK system, in general, outperforms the CSK system in for height the data transmission rate various spreading factors values. This system serves the communications and security departments such as military installations.

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