Signal Properties under Multi-Carrier Chaos –Shift Keying

Salsabeel S. Hasan and Zahir M. Hussain
Faculty of Computer Science & Mathematics, University of Kufa; Najaf; Iraq
salsabils.alkriti@student.uokufa.edu.iq
zahir.hussain@uokufa.edu.iq

Abstract. In recent years, increased demand for high-quality multimedia services requires increasing the wireless communications application data rates and be more reliable and secure. To meet this request, the researches related to Multi-Carrier (MC) transmission technologies have made considerable efforts in recent years because multi-carrier techniques can improve the data transmission rates. In this research, an overall study on performing Multi-Carrier Chaos Shift keying by using a technique Orthogonal Frequency Division Multiplexing (OFDM) is presented. A multi-carrier system simulation is designed because of the limited speed provided by Chaos Shift keying (CSK) due to the spreading factor. To increase security in this system; the chaotic sequence was generated by proposed to modify on one of the well-known chaos generators that is a tent map. The performance test and the security analysis were carried out using the Bit Error Rate (BER), Mean Squared Error (MSE), correlation test; the chaotic characteristics of the chaos generators sequences using are tested the Lyapunov Exponent. Results have showed the proposed tent map the autocorrelation is like a delta function, so that it appears as a noise that is difficult to discern the information carried by signal, it is much more sensitive to change the initial state and control parameters, where the proposed tent map provides better chaotic properties for encryption such as greater Lyapunov exponent, compared with well-known chaos maps (Logistic map1, Tent map, Quadratic map), it provides a lower Bit Error Rate (BER) performance than a tent map. In addition, the proposed method to multi-carrier CSK system with various Spreading Factors (SF) values outperforms the CSK system in improving the data transmission rate.

Keywords. Chaos, Tent Map, Chaos Shift Keying, Orthogonal Frequency Division Multiplexing, Multi-Carrier

1. Introduction
The next generation of wireless communications systems demands higher to data rates transmission in order to meet the higher request for quality services. In the last few decades, research into wireless digital communications techniques has expanded rapidly, resulting in more reliable wireless communication systems operating at higher spectral efficiencies [1]. 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 [2]. The Orthogonal Frequency Division Multiplexing System (OFDM) is one of the most significant techniques that proved to be effective. The OFDM represents a special form of multi-carrier transmission, where it first proposed this technique in 1966 [3].

This technique has existed for several decades. It has grown in recent decades from textbooks and research laboratories into a practical modern communication system [4], it is a versatile, effective technique of modulation is commonly used today wireless and wired systems, and also it is the basic transmission scheme in fourth-generation 4G and five-generation 5G [5]. The baseband signal without the use of modulation techniques can't be transmitted in the OFDM such as Modulation of quadrature amplitude M-QAM [6], and in the present case, there will be use of 4-QAM and 16-QAM modulation in the simulation. Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) algorithms are used to decode the signal at the transmitter and receiver respectively to multiplex the signal together. OFDM systems incorporate a guard interval to avoid the inter-symbol interference (ISI) induced by the propagation path [7]. It has been shown that chaos-based communication systems bring certain advantages over conventional communication systems. There are, however, still plenty of issues to solve before chaos-based systems can be put to a practical use. Research on the use of Chaos Shift Key (CSK) to improve contact with Chaos thus allows for more from practical development. In this field, further research is needed, and there is plenty of space for further study and development. A chaos-based communication framework may also improve particularity, security and the probability of detection depending as chaotic sequences, unlike pseudorandom sequences, totally non-periodic [8]. 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 [9]. The number of chaotic sequences that can be generated by a single formula is not restricted because of its bifurcation behavior depending on the initial condition and will not repeat itself. These features provide an increase in system capacity and security performance [10].

The combination of MC transmission and digital chaos-based digital modulation can perfectly solve the problem of delay line [11] and can also inherit several merits originally reported from multi-carrier spread spectrum (MC-SS) schemes [12], such as high spectral efficiency, robustness, and elasticity. In this study, it is focus on a Multi-Carrier Chaos Shift Keying (MC-CSK). An efficient Chaos generator that can be used to generate CSK sequences is a logistic map and tent map [13]. In this paper, it is study and test chaos generators (logistic map, tent map, and quadratic map,) to determine chaotic sequences shown a noise-like properties, so that it appears as a noise that is difficult to discern the information carried by this signal and an adjustment for chaotic sequences that does not show noise-like properties (far from a delta function) to generate chaotic sequence has more security in transmission, and it is proposed to design a multi-carrier chaos shift keying system simulation using OFDM that represents a special form of multi-carrier transmission because CSK is slow due to the spreading factor.

2. LITERATURE REVIEW

In [14] 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 [11] 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 [15]
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).

3. BACKGROUND

3.1. Chaos Shift Keying (CSK)

Chaos is a word derived from ancient Greek, which denotes chaotic actions and the universe or order
opposite. The word "Chaos" in Chaos theory, however, is not an antithesis of the universe or the absence
of Order has, in truth, a very subtle order in itself which is not quite apparent as ordered structures. The
history of Chaos in the scientific world has to be traced back to the time when Newton used his newly
discovered differential equation to solve the two-body problems in the universe [16]. The theory of
chaos is a blanket theory that encompasses all fields of science, and it appears everywhere in today's
world: mathematics, physics, biology, Finance, correspondence, computers, and music too. Chaotic
signals are neither periodic nor quasi-periodic in the time domain, unpredictable in the long term. This
unpredictable phenomenon manifests itself in the frequency domain as a wideband noise-like power
spectrum. Classification of the chaotic dynamic system into continuous-time and discrete-time [17]. Due
to its simplicity and high degree of unpredictability, CSK has proved in recent years to offer a potential
advantage over traditional methods. CSK was initially proposed in [18]. Where in binary chaos shift keying modulation, chaotic signals carrying different bit energies are used to transmit
binary information [19][20][21][22][23][24].

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" Figure.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, $k = 1, 2, \cdots; l = 1, 2, \cdots; g_{k,i}$ is the chaotic sample of the k-th component, with the expected value $E(g_{k,i}) = 0$. 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 $\alpha_i$ is expressed as $s = \alpha_t g_k$, where $i = 1, 2, \cdots; g_{k,i}$ is the carrier and $s_k = [s_{k,1}, s_{k,2}, \cdots, s_{k,2\beta}]$ refers to the total baseband signal transmitted during the k-th bit duration. Note that both the numbers $S_{k,1}$ 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 $r_k = [r_{k,1}, r_{k,2}, \cdots, r_{k,2\beta}]$ representing the received CSK during the k-th transmission period (i.e., bit duration), $y_i$ (demodulator output) is calculated using:

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

The decoded bit then is determined on the basis of the rule of hard-decision: $\alpha_i = +1$ if $y_i \geq 0$ and
$\alpha_i = -1$ otherwise. The transmitted signal is given by [25]:

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

Chaos-based communication systems can be classified into two principal systems categories,
coherent and non-coherent structures [26]. The receiver has to return the production of the chaotic carrier
for demodulation incoherent systems while in the non-coherent system demodulation is done solely on the basis of the received signal [20].

3.2. Chaotic Map

In the past, a great number of various forms of mathematical models have been derived and investigated into chaos theory. Generations of messy maps have come from several different directions. This can be a complex or simple system of control, a mathematical equation like a differential equation, or a basic circuit modeling like circuit Chua [25].

3.2.1. Logistic Map I (LCGI)

One of the simplest chaotic logistic maps used for chaotic sequences generation is given by [20] [27] $g_{n+1} = 1 - 2g_n^2$, initial value $g_0 = g(0)$ lies in the interval $(1, -1)$ [15].

3.2.2. Tent Map

It is defined as a chaotic map, as:

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

Regardless of this feature, the tent map is partially linear, which makes the tent map simpler to be analyzed than the logistic map. While the form of the tent map is simple and the equations for some parameter values are linear, the map can produce complex and chaotic behavior when the system parameter is in $(0, 1)$, in which case the variable $x_n$ will be in $(0, 1)$. The tent map and the logistic map are conjugates of topology. The system is chaotic when $\alpha$ varies at $(0, 1)$. The system is especially in a short-cycle state such as $(0.2, 0.4, 0.8)$ when is $\alpha = 0.5$, the system is simple in this case, and low in complexity, Figure 2. Accordingly, for the implementation of the tent map method, the initial value and parameter buildable can be selected [28].

Figure 1. Chaos Shift Keying (CSK) system

Regardless of this feature, the tent map is partially linear, which makes the tent map simpler to be analyzed than the logistic map. While the form of the tent map is simple and the equations for some parameter values are linear, the map can produce complex and chaotic behavior when the system parameter is in $(0, 1)$, in which case the variable $x_n$ will be in $(0, 1)$. The tent map and the logistic map are conjugates of topology. The system is chaotic when $\alpha$ varies at $(0, 1)$. The system is especially in a short-cycle state such as $(0.2, 0.4, 0.8)$ when is $\alpha = 0.5$, the system is simple in this case, and low in complexity, Figure 2. Accordingly, for the implementation of the tent map method, the initial value and parameter buildable can be selected [28].
3.2.3. Quadratic Map

The quadratic map is chaotic because it is not linear. Since it contains an equation determines the system's behavior so it is deterministic. When the initial value $x_0$ changes, a completely different behavior results for the map, this equation can be described [29]:

$$x_{n+1} = \alpha - (x_n^2)$$  \hspace{1cm} (1)

Where $\alpha$ is a chaotic parameter, and $n$ an iteration number. The system is chaotic when $\alpha = [1.5, 2]$.

3.3. Lyapunov Exponent

Lyapunov Exponent is a number that describes the dynamics of path evolution which gives the average rate of convergence or distance in the phase space between two adjacent paths. Its value is either positive, negative, or zero. In the case of negative values, this means that the two paths are adjacent to each other. This means that system doesn't chaotic, a positive Lyapunov exponent implies that the volume of the system phase extends and folds in one direction such that the attractor's originally adjacent trajectories become increasingly irrelevant, and the system's long-term behavior becomes unpredictable, namely the such-called initial value sensitiveness. The motion is in a chaotic state at this time and zero means the stable system [28] [29]. In one-dimensional maps the Lyapunov exponent can be defined as follows:

$$\lambda_{x_0} = \lim_{n \to \infty} \frac{1}{n} \sum_{i=1}^{n} \ln |f'(x_i)|$$ \hspace{1cm} (2)

Where, $f'$ is the derivative of the function $f$.

3.4. Correlation Analysis

LCG1 map revealed noise-like features as show in Figure 3, correlating functions of chaotic signals with time-delay vector. (a) auto correlation with one initial condition, (b) cross-correlation with two initial condition that are nearby. Figure 4 illustrate another generator tent map does not show noise-like properties (far from a delta function). Because of the delicate reliance on initial conditions and the random behavior of chaotic signals in addition to their broadband spectrum, it was assumed that information could be effectively concealed in chaotic signals in order to make long-term predictability and impossible [15]. In this study, it is used mean square error (MSE) to measure similar between autocorrelation of chaotic maps with delta function because MSE has become one of the most commonly used metrics in the Similarity Measures for 1D Signals due to its simple formulation and straightforward interpretation [30]. MSE calculates the average error squares, which is the average square difference between measured values and estimates. The mathematical form is [31]:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (A_i - \bar{A})^2$$ \hspace{1cm} (6)
Figure 3. correlating functions of chaotic signals with time-delay vector. (a) auto correlation with one initial condition, (b) cross-correlation with two initial condition that are nearby. LCG1 shown a noise-like properties.

Figure 4. correlating functions of chaotic signals with time-delay vector. (a) auto-correlation with one initial condition, (b) cross-correlation with two initial condition that are nearby. the tent map does not show noise-like properties (far from a delta function).

3.5. OFDM
Chang initially proposed the OFDM system in1966 [3]. The data will originate as a stream, to be transmitted over the orthogonal carriers. This serial data is the mapping of data by QAM baseband modulator after parallel transformation applied to the modulator, the step preceding the data arrives at IFFT level. OFDM systems used IFFT and FFT algorithms at the transmitter and the receiver respectively to multiplex the data signals and transmit them simultaneously over a number of subcarriers. In the discrete time the mathematical form of IFFT as follows [32]:

\[
x_k = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} X_m e^{j2\pi km/N}
\]

Where, \(x_k\) is a signal represented in a discrete time domain, whereas \(X_m\) 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 [3.3]. 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 [34-4]:

\[
Y(m) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y(n) e^{-j2\pi km/N} + W(n)
\]

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

The factors that are important for deciding how effective the receiver would be when processing the incoming signal are the signal-to-noise ratio (or, better, Eb/No), the data rate and the bandwidth. With other constant factors, the following statements [affected] are true [3.5]:

- Raising the data rate raises the bit error rate (BER)
- The rate of bit error decreases with an increase in SNR.
- Increasing the bandwidth allows the data rate to increase.
4. RESEARCH METHOD
The approach proposed for this study was split into two stages. In transmitter, the first stage includes input data, pre-processing of the data, then generating the chaotic sequence by the proposed tent map by modifying tent map without changing the chaotic behavior (linear transformation) for increasing the security level, the proposed tent map be in the form of the following equation:

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

$$x = 2 \times x - 1$$  \hspace{1cm} (9)

then modulation binary information by using CSK is generated using the proposed tent map. The second stage includes transmission for modulation data by CSK via the MC-CSK system using OFDM technique. Figure 5 illustrates the principal stages of the system proposed CSK-OFDM. After gray encoding the sending process begins with the use of 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 4-QAM or 16-QAM, and transferring from parallel to serial. After that gray decode and CSK-demodulation, then applied the data words are taken as the same word size of the original data after the preceding operations.

5. RESULTS AND DISCUSSION

5.1. Lyapunov Exponent
The control parameter is \(a\). When parameter \(a\) 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 Table 1 that shows the highest Lyapunov Exponent values for sequences of different chaos systems for versus parameter \(a\). Figure 6 shows Lyapunov Exponent for the proposed tent map with control parameter \(a\). this suggests that the proposed system maintains a high sensitivity to the initial value as shown in Figure 7. While the tent map when \(a\) is equal to 0.5, the tent map possesses the highest Lyapunov Exponent is equal to (0.69) as shown in Figure 8. In addition, results illustrate in Table 1, the proposed tent map has the highest Lyapunov Exponent compared with sequences of different chaos maps (LCG1 map, tent map).
map, quadratic map), and it becomes the system's extended-duration behaviour becomes unpredictable. Figure 9 shows Lyapunov Exponent for the LCG1 and Figure 10 shows Lyapunov Exponent for the quadratic map with control parameter $\alpha$.

Table 1. The highest Lyapunov Exponent to sequences different chaos systems for versus parameter $\alpha$

| Chaotic Map         | Parameters | The highest Lyapunov Exponent |
|---------------------|------------|-----------------------------|
| The Proposed Tent Map | 0.5        | 1.3849                      |
| Tent Map            | 0.5        | 0.6925                      |
| LCG1 Map            | 2          | 0.6700                      |
| Quadratic Map       | 2          | 0.6935                      |

Figure 6. Lyapunov Exponent for the proposed tent map

Figure 7. Chaos is sensitive to initial conditions for the proposed tent map

Figure 8. Lyapunov Exponent for the tent map

Figure 9. Lyapunov Exponent for the logistic map1 (LCG1)

Figure 10. Lyapunov Exponent for the quadratic map
5.2. Correlation Analysis

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. We can transmit information in confidentiality and more privacy, it is calculate the correlation of the signal produced by the generator, showing the generator that closest for delta function, so that it appears as a noise that is difficult to discern the information carried by this signal 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) the autocorrelation is like a delta function shown a noise-like properties as shown in Figure 11 and table 2. While tent map does not show noise-like properties (far from a delta function) as shown in Figure 12. 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, LCG1, and the quadratic map. Therefore, the proposed tent map has a better chaotic feature, Figure 13 shows the autocorrelations of the sequences that are generated by LCG1 and quadratic map.

![Figure 11](image1.png)

(a) correlating functions of chaotic signals with time-delay vector. (a) auto correlation with one initial condition, (b) cross-correlation with two initial condition that are near by, the proposed tent map shown a noise-like properties.

![Figure 12](image2.png)

(a) correlating functions of chaotic signals with time-delay vector. (a) auto-correlation with one initial condition, (b) cross-correlation with two initial condition that are near by, the tent map does not show noise-like properties (far from a delta function).

![Figure 13](image3.png)

(a) Auto-correlations of the sequences (a) LCG1 map. (b) Quadratic map
Table 2. The mean square error between autocorrelation of chaotic map and delta function

| Chaotic Map  | Parameters | Data length | MSE   | Data length | MSE   |
|--------------|------------|-------------|-------|-------------|-------|
| The Proposed Tent Map | 0.5 | 100 | 6.1254 | 1000 | 47.7417 |
| Tent Map     | 0.5 | 100 | 202   | 1000 | 21141  |
| LCG1 Map     | 2   | 100 | 12.0186 | 1000 | 140.9  |
| Quadratic Map | 2   | 100 | 149   | 1000 | 1961   |

5.3. Performance of CSK using the Proposed Tent Map and Tent Map

The performance of the generated CSK system using the proposed tent map and the tent map can be measured in this section to case both coherent CSK and non-coherent CSK when intentionally estimating the initial condition (IC) and security parameter ($a$) to simulate the method that an attacker would use. The following results show the BER for SNRs of [-20, 20] range and SF=10. The BER is used to measure the effect of channel imperfections on the transmitted signal obtained by counting the number of bits received incorrectly and dividing this number by the number of bits transmitted total. Simulation tests of comparison and measurement of CSK system efficiency under Gaussian noise can be realized. It is noticed from Figures [14 -16] the proposed tent map has a lower error in the coherent CSK and it has a higher error in the non-coherent CSK compared with a tent map. In Figure 17, it is noticed that the proposed tent map has a higher error compared with chaos maps in the non-coherent CSK. Therefore, the proposed chaos sequence is more secure and has low interception potential.

Figure 14. BER Performance of coherent CSK under AWGN using the proposed tent map ($a$ =0.5 and IC=0.7) and Tent map ($a$ =0.5 and IC=0.7)

Figure 15. BER Performance of non-coherent CSK under AWGN using the proposed tent map (same $a$ =0.5 and estimating IC=0.70001) and Tent map (same $a$ =0.5 and estimating IC=0.70001)

Figure 16. BER performance of non-coherent CSK under AWGN using the proposed tent map (estimation $a$ =0.56 and same IC=0.7) and tent map (same IC=0.7, and estimating $a$ =0.56)

Figure 17. BER performance of non-coherent CSK when estimating IC=0.70001 under AWGN
In Figure 18 shows demonstration of non-coherent CSK output on the image using the proposed tent map and tent map with SF=3 under AWGN noise, it is clear that a slight shift in initial condition results in a blurred image. Less distortion in image in the tent map can be obtained if an initial condition estimate is used. It is concluded that the proposed tent map more stable than the tent map since a small change in initial condition results in a completely ambiguous image and BER is very high.

![Original Image](image1.png) ![The Proposed Tent Map](image2.png) ![Tent Map](image3.png)

**Figure 18.** Non-coherent CSK system for received image using the proposed tent map and tent map

### 5.4. Simulation of CSK-OFDM and CSK System

The performance of the multi-carrier CSK system can be measured using the CSK generated by the proposed tent map and send the signal via the multi-carrier system using OFDM under Gaussian noise with different spreading factors. The following results show the BER for SNRs of [-20, 30] range. In Figure 19 it is seen that a lower bit error rate is obtained when CSK is in the AWGN environment and its spreading factor is increased, resulting in a decrease in the effective signal noise that was sent out. Conversely, the BER for increased if the SF is set to a small value. It is noticed that the BER performance of CSK-OFDM with different spreading factors. The CSK-OFDM system when increasing M-QAM size and number of sub-carriers (FFT), it does lead to increased data rate but will increase error as well. Thus 4-QAM has BER performs better than 16-QAM as shown in Figures 20, 21 and when a number of sub-carriers (FFT) are equal (8) has BER performs better than when number of sub-carriers are equal (16). But 16-QAM outperform 4-QAM and also FFT=16 better than FFT=8 in increased data rate. We can compare between both systems performance CSK-OFDM system and the CSK system when SF=5 and SF=10. First, we can see that the CSK-OFDM system with different spreading factors outperforms CSK in improving data rate significantly, but at the expense of more error (BER). Second, decrease spreading factor will improve data rate in CSK-OFDM, increasing spreading factor 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 Figures [22-27].
Figure 19. BER performance of CSK under AWGN

Figure 20. BER performance of CSK-OFDM under AWGN, 16-QAM, FFT=8

Figure 21. BER performance of CSK-OFDM under AWGN, 4-QAM, FFT=8.

Figure 22. BER performance of CSK and CSK-OFDM under AWGN, 4-QAM, FFT=8, SF=5.

Figure 23. BER performance of CSK and CSK-OFDM under AWGN, 4-QAM, FFT=8, SF=10.

Figure 24. BER performance of CSK and CSK-OFDM under AWGN, 4-QAM, FFT=16, SF=5.
Figure 25. BER performance of CSK and CSK-OFDM under AWGN, 4-QAM, FFT=16, SF=10. OFDM under AWGN, 16-QAM, FFT=8, SF=5.

Figure 26. BER performance of CSK and CSK-OFDM under AWGN, 16-QAM, FFT=8, SF=10.

In Figure 28 and Figure 29 an image over the CSK-OFDM system can be sent after applying the preprocessing to the input image. Where FFT size is (8) and the modulation technique is 4-QAM and SF=5, with increment of fifteen realizations with different SNR states (-20, 0, 30) in dB.

Original Image               Received, N-FFT OFDM, M-QAM, N=8, M=4, SNRdB = -20, Lp=1.  QAM, N=8, M=4, SNRdB=0, Lp=1.

Figure 28. Received image with different SNR states (-20, 0) in dB

Figure 29. Received image, N-FFT OFDM, M-QAM, N=8, M=4, SNRdB=30, Lp=1.

6. CONCLUSION
The performance of Multi-Carrier Chaos -Shift keying is extensively studied by using OFDM for under AWGN noise with various values of spreading factor (SF). The chaotic sequence was created generated
for the CSK system by using the proposed tent map. We conclusion the proposed tent map is the closest to the delta function more than LCG1, the tent map, and the quadratic map, and it is very sensitive to initial condition and parameter value, this property is very important for communications security that prevents attackers from predicting value or altering the signal. This chaotic sequence entirely non-periodic unlike random sequences, so the proposed tent map can encrypt information, 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 method to the Multi-carrier CSK system, in general, outperforms the CSK system in improving the data rate for various spreading factors values. And decrease spreading factor will improve data rate in CSK-OFDM, increasing spreading factor will improve bit error rate in both CSK and CSK-OFDM, but decreases data rate.

References
[1] Haitham J. Taha and Mohd Fadzli, Mohd Salleh, "Multi-carrier transmission techniques for wireless communication systems: a survey," Wseas transactions on communications, vol. 8, no. 5, pp. 457--472, 2009.
[2] Khalid El Baamrani, Abdellah Ait Ouahman and Said Allaki, Rate adaptive resource allocation for OFDM downlink transmission," AEU-International Journal of Electronics and Communications, vol. 61, no. 1, pp. 30--34, 2007.
[3] Taewon Hwang, Chenyang Yang, Gang Wu, Shaoqian Li and Geoffrey Ye Li, "OFDM and its wireless applications: A survey," IEEE transactions on Vehicular Technology, vol. 58, no. 4, pp. 1673--1694, 2008.
[4] Louis Litwin and Michael Pugel, "The principles of OFDM," RF signal processing, vol. 2, pp. 30--48, 2001.
[5] Erik Dahlman, Stefan Parkvall and Johan Sköld, 5G NR: The next generation wireless access technology, Academic Press, 2018.
[6] Sangeeta Jajoria, Sajjan Singh and S. V. A. V. Prasad, "Analysis of BER performance of OFDM system by Adaptive Modulation," International Journal of Recent Technology and Engineering (IJRTE), vol. 1, no. 4, 2012.
[7] Pavan Kumar and Amita Kumari, "BER analysis Of BPSK, QPSK, 16-QAM & 64-QAM based OFDM system over Rayleigh fading channel," IOSR J Electron Commun Eng (IOSR-JECE), vol. 11, no. 4, pp. 66--74, 2016.
[8] Lawrence E. Larson, Jia-Ming Liu and Lev S. Tsimring, Digital communications using chaos and nonlinear dynamics, Springer, Berlin, Germany, 2006.
[9] Francis C.M. Lau and Chi K. Tse, Chaos-based digital communication systems, Operating Principles, Analysis Methods and Performance Evaluation (Springer Verlag, Berlin, 2004), 2003.
[10] Yuu-Seng Lau and Zahir M. Hussain, "Chaos shift keying spread spectrum with multicarrier modulation for secure digital communication," WSEAS Transactions on Communications, vol. 4, no. 1, 2005.
[11] Hua Yang, Wallace K. S. Tang, Guanrong Chen and Guo-Ping Jiang, "Multi-carrier chaos shift keying: System design and performance analysis," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 64, no. 8, pp. 2182--2194, 2017.
[12] John A. C. Bingham, "Multicarrier modulation for data transmission: An idea whose time has come" IEEE Communications magazine, vol. 28, no. 5, pp. 5--14, 1990.
[13] Yuu-Seng Lau and Zahir M. Hussain, "A new approach in chaos shift keying for secure communication," in Third International Conference on Information Technology and Applications (ICITA'05), Sydney, New South Wales, 2005, July.
[14] Shilian Wang and Zhili Zhang, "Multicarrier chaotic communicaions in multipath fading channels without channel estimation," Aip Advances, vol. 5, no. 1, p. 017139, 2015.
[15] Safaa T. M. Jawad, Zahir M. Hussain and Katrina Neville, "A Study on the Performance of CSK under Noisy Conditions," International Journal of Applied Engineering Research, vol. 12, no.
22, pp. 11840–11846, 2017.

[16] Rupak Kharel, "Design and implementation of secure chaotic communication systems," Ph.D Thesis, Northumbria University, Newcastle Upon, England, UK., 2011.

[17] Dennis Luke Owuor, "Chaos-based secure communication and systems design," MSc Thesis, Tshwane University of Technology, Pretoria, South Africa, 2012.

[18] Hewe Dedieu, Michael Peter Kennedy and Martin Hasler, "Chaos shift keying: modulation and demodulation of a chaotic carrier using self-synchronizing Chua's circuits," IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing, vol. 40, no. 10, pp. 634–642, 1993.

[19] Francis C. M. Lau, Chi K. Tse, Ming Ye and Sau F. Hau, "Coexistence of chaos-based and conventional digital communication systems of equal bit rate," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 51, no. 2, pp. 391–408, 2004.

[20] Francis C.M. Lau and Chi K. Tse, Co-existence of chaos-based and conventional digital communication systems, Bangkok, Thailand, Proceedings of the 2003 International Symposium on Circuits and Systems (ISCAS'03), May 25-28, 2003, pp. 204-207.

[21] Géza Kolumbán, "Theoretical noise performance of correlator-based chaotic communications schemes," IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 47, no. 12, pp. 1692–1701, 2000.

[22] Géza Kolumbán, Michael Peter Kennedy, Zoltán Jákó and Gábor Kis, "Chaos Communications With Correlator Receivers: Theory and Performance Limits. Proc. IEEE, vol. 90, pp. 711-732, 2002.

[23] Andreas Abel and Wolfgang Schwarz, "Chaos communications-principles, schemes, and system analysis" Proceedings of the IEEE, vol. 90, no. 5, pp. 691–710, 2002.

[24] Yuu-Seng Lau, "Techniques in secure chaos communication" Ph.D Thesis, RMIT University, Melbourne, Australia, 2006.

[25] Raghad I. Hussein, Zahir M. Hussain and Salah A. Albermany, "Performance of Differential CSK under Color Noise: A Comparison with CSK," Journal of Engineering and Applied Sciences, vol. 15, no. 1, pp. 48–59, 2020.

[26] Georges Kaddoum, "Wireless chaos-based communication systems: A comprehensive survey," IEEE Access, vol. 4, pp. 2621–2648, 2016.

[27] Sathyanarayan. S. Rao and . Stephen. P. Howard"Correlation performance of chaotic signals in spread spectrum systems" 1996 IEEE Digital Signal Processing Workshop Proceedings, pp. 506--509, 1996.

[28] Kehui Sun, Chaotic secure communication: principles and technologies, 1st Edn.,Walter de Gruyter GmbH and Co KG, 2016.

[29] Noha Ramadan, Hossam Eldin H. Ahmed, Said E. Elkhamy and Fathi E. Abd El-Samie, "Chaos-based image encryption using an improved quadratic chaotic map," American Journal of Signal Processing, vol. 6, no. 1, pp. 1--13, 2016.

[30] Richard Dosselmann, and Xue Dong Yang, "A comprehensive assessment of the structural similarity index," Signal, Image and Video Processing, vol. 5, no. 1, pp. 81–91, 2011.

[31] Zhou Wang and Alan C. Bovik, "Mean squared error: Love it or leave it? A new look at signal fidelity measures," IEEE signal processing magazine, vol. 26, no. 1, pp. 98–117, 2009.

[32] Khaizuran Abdullah and Z. M. Hussain, "Simulation of models and BER performances of DWT-OFDM versus FFT-OFDM," Discrete Wavelet Transforms-Algorithms and Applications, 2011.

[33] Khaizuran Abdullah and Z. M. Hussain, "Studies on dwt-ofdm and fft-ofdm systems," in IEEE International Conference on Communication, Computer and Power(ICCCP), 2009.

[34] Ghassan Muslim Hassan, Khairul Azm Ab Bakar and Mohd Rosmadi Mokhtar, "Sending Image In Noisy Channel Using Orthogonal Frequency Division," Journal of Theoretical & Applied Information Technology, vol. 96, no. 12, 2018.

[35] Williant Stallings, Wireless communications and networks, Pearson Education India, 2009.