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OFDM+CDMA+Stego = Secure Communication: A Review

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ABSTRACT
Orthogonal Frequency Multiplexing (OFDM) is a multicarrier modulation technique which allows sub channel overlapping for efficient utilization of available frequency spectrum. Demand for high data rate wireless communication is rapidly increasing and there is a need for a technique which overcomes the problems like Intersymbol Interference (ISI) and frequency selective fading. OFDM overcomes the problems of high data rate wireless communication by converting high rate data stream in to number of parallel low rate data streams and this will be a suitable modulation/multiplexing technique for advanced wireless communication systems. In this paper, a review has been made, to detail the progress on OFDM since 1870, it also explains the basic building blocks of OFDM, Code Division Multiple Access (CDMA) and Multi Carrier Code Division Multiple Access (MC-CDMA) Schemes and how it could be modified suitably?, to carry additional confidential Information using steganography.

Key words: OFDM, CDMA, MC-CDMA, information hiding, steganography

INTRODUCTION
The very basic idea and the long history of OFDM came into existence in the year 1870 when Thomas Edison invented Multiplex telegraph (Weinstein, 2009). Then the concept of FDM transmission was introduced by Bell (1876). FDM transmission for analog telephony was first demonstrated in the year 1910 by Schwartz (2008). It was then implemented in 1918 by AT&T. The principle behind OFDM was proposed by Chang (1970) and analysis on the performance of efficient parallel data transmission system over wireless channels was reported by Saltzberg (1967). Larger sub channels increases the cost and complexity of FDM systems which utilizes (Weinstein and Ebert, 1971) Discrete Fourier Transform (DFT) as it eliminates the need of equalization methods and a reduction in multipath fading is achieved.

In OFDM, processing of signals can be performed in digital domain and the latest developments in VLSI technology has enabled high speed large size FFT (Bidet *et al*., 1995) chips to be economically affordable. In 1980's OFDM technique was introduced and used in high speed modems. In this system a pilot tone was used for the stabilization of carrier frequency and clock frequency and error correcting codes were implemented to reduce the required carrier to noise ratio. Cimini (1985) introduced the concept of the cyclic prefix which forms a pivotal point in the OFDM formulation chain to combat the effect of frequency selective fading and

Doppler shift in mobile channel. COFDM technique was harnessed by incorporating the addition of a guard interval (Vahlin and Holte, 1994).

The multimedia data transmission for various data types is provided by Van Nee and Prasad (2000). Speth *et al.* (1999) analyses the problem of multipath channels and multicarrier system in his paper on "OFDM Receivers for Broadband Transmission". In 1960's, several military systems were using OFDM (Mosier and Clabaugh, 1958; Zimmerman and Kirsch, 1967). Hirosaki (1981) realized the OFDM technique utilizing multiplexed QAM with DFT. Telephone networks using various high speed modems were developed by Keasler *et al.* (1980). In 1990's, COFDM was studied for broadband data communication, High bit rate HDTV terrestrial broadcasting, Digital Subscriber Lines (HDSL),Very High Speed Digital Subscriber Lines (VHDSL), Asymmetrical Digital Subscriber Lines (ADSL), Digital television and Digital Audio Broadcasting (DAB) (Sari *et al.*, 1995; Chow *et al.*, 1991a, b; Hara *et al.*, 1996; Hara and Prasad, 1997). Rappaport (2002) outlined the advantages of Multicarrier Communication and the advancement in VLSI technology in realizing the OFDM system on "Wireless Communication" (Pandey *et al.*, 2002) describes the VLSI implementation of OFDM.

In 1993, a group of researchers Hara and Prasad (1997) proposed a new hybrid combination by integrating Code Division Multiple Access (CDMA) and OFDM. Some of the techniques proposed were Multicarrier CDMA (MC-CDMA), Multitone CDMA (MT-CDMA) and MC-DS-CDMA (Fazel, 1993; DaSilva and Sousa, 1993; Nithyanandan and Dananjayan, 2006). Direct Sequence CDMA is a spread-spectrum communication technique (Yang and Hanzo, 2003; Proakis, 2000). DS-CDMA systems (Viterbi, 1995; Lee and Miller, 1998) are capable of supporting a multiplicity of users within the same bandwidth by assigning different typically unique user-specific codes to different users for their communications, in order to be able to distinguish their signals from each other at the receiver. Thenmozhi *et al.* (2011) enumerated Space Time Frequency coded (STF) OFDM for broadband wireless communication systems.

Spread-spectrum techniques were developed originally for military guidance and communication systems (Scholtz, 1982). During late 1970s, the employment of spread-spectrum techniques was proposed for efficient cellular communication (Cooper and Nettleton, 1978). The MC-CDMA technique is believed to be able to outperform the other techniques such as DS-CDMA mainly due to the reduction in complexity of the receiver while at the same time providing equal and even better performance. A detailed study on Multicarrier Code Division Multiple Access (MC-CDMA) had been carried out and the description of MC-CDMA system was given by (Zou and Wu, 1995). 3G wireless communication explored to meet the demand of wireless communications was suggested by Meng *et al.* (2008), Hemalatha *et al.* (2009) and Wu *et al.* (2010a), even this could be used in Wi-Fi (Hemalatha *et al.*, 2011).

Since there is no such survey or review has been made on the existing spread spectrum use in secure communication. An optimistic maiden effort has been taken, to study the progress on OFDM, CDMA, MC-CDMA and spread spectrum based steganography for secure communication.

OFDM SYSTEM DESCRIPTION

OFDM (Orthogonal Frequency Division Multiplexing) Akansu *et al.* (1998) is a technique of mapping the information utilizing the bandwidth sharing concept. So often it's a combination of modulation and multiplexing techniques (Chang and Gibby, 1968). In OFDM first the signal splits into independent channels (Saltzberg, 1967) and is modulated by information and then demultiplexed to create OFDM carrier. It's even a special form of FDM (Frequency Division Multiplexing) with subcarriers (Casas and Leung, 1991) being orthogonal to each other. It's a

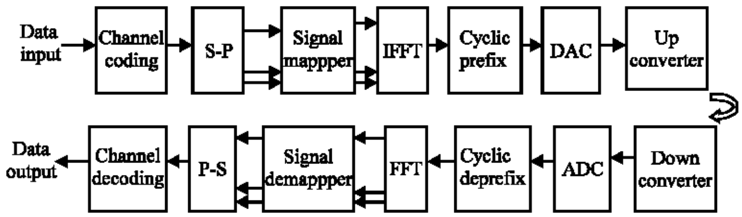

Fig. 1: Block diagram of OFDM system

Table 1: Parameters of OFDM

Parameters	Specifications
OFDM symbol time	4 μsec
Data rates	6 to 48 Mbps
Modulation adopted	BPSK, QPSK, QAM
Guard duration	¼ of symbol time
Error control codes	Convolutional codes
FFT period	3.2 μsec
FFT size	64 (52 subcarriers- 48 for data, 4 for pilots)
Frequency spacing of subcarriers	20 MHz/64

special case of multi-carrier modulation with high data rate capability (Weinstein and Ebert, 1971). OFDM system's diagram has been presented in Fig. 1.

In OFDM the serial data stream is initially formatted based on the required transmission, (1 bit/word for BPSK and 2 bits/word for QPSK and 3 bits/word for QAM) and converted into a parallel format by assigning each data with one carrier. It increases the symbol duration (Chuang, 1987) by dividing the entire channel bandwidth into many narrow orthogonal sub-channels (Doelz *et al.*, 1957). Hence the symbol duration becomes much larger than the channel impulse response which will greatly mitigate the effects of intersymbol interference (ISI) in multipath channel (Zhaogan *et al.*, 2007). Based on the modulation employed the data on each symbol is mapped to a phase angle (Hirosaki, 1981). Applying IFFT to the sequence results in frequency to time domain conversion. To each OFDM symbol a guard period is added at the beginning of each symbol (Kalet, 1989), cyclic prefix is a just the cyclic extension of the transmitted symbol. It is inserted between each OFDM symbol which eliminates ISI almost completely (Haque *et al.*, 2008). Since it is larger than the maximum time delay it maintains the orthogonality between sub-carriers (Rappaport, 2002). Parameters of OFDM has been presented in (Table 1).

The symbol duration is $T_{total} = T_{FFT}+T_{GI+}T_{win}$. The insertion of guard interval will reduce data throughput so it is usually less than T/4 (Fig. 2).

The symbols are converted into a serial time waveform. The base band signal of the OFDM is then applied to a channel model which is normally AWGN.

The kth OFDM signal can be written as:

$$S_{RFk}(t-kt)=\begin{cases} \text{Re}\,[w(t-kt)\sum_{i=N/2}^{N/2} x_{ik}\, e^{i2\pi}\left(f_c+\frac{i}{T_{FFT}}\right)(t-kt) \\ kT-T_{win}-T_G \le t \le kT \le +T_{FFT}+T_{win} \text{ otherwise zero} \end{cases} \quad (1)$$

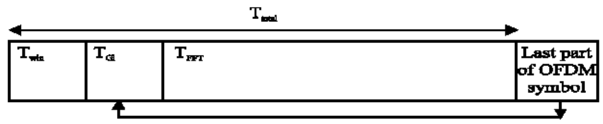

Fig. 2: Guard interval in OFDM

x_{ik}-Symbol modulated on ith subcarrier on kth OFDM symbol, f_c-centre frequency of the spectrum, T_{FFT}-FFT time, T_{win}-window interval, T_G-guard time. F-frequency spacing between adjacent subcarriers, T-time between two OFDM symbols, K-index on transmitted symbol, I-index on subcarriers, N-FFT points.

The receiver will perform the reverse operation of the transmitter. Initially the guard period is detached from each symbol (Cimini *et al.*, 1996) and FFT is applied to find the transmitted spectrum. The phase angle of each carrier is then converted back to the data by demodulating the received phase. The data words are combined again to form the original data.

CDMA system description: In data communication several transmitters are allowed to send information simultaneously (Casas and Leung, 1991) over a single communication channel which allows several users to share the bandwidth called as multiple access scheme (Venkatesan and Ravichandran, 2007). CDMA is a special form of Spread Spectrum (SS) coding technology (Cooper and Nettleton, 1978) where each transmitter is assigned a code allowing multiple users to be multiplexed over the same channel (Britto and Sankaranarayanan, 2006). Yue (1983) summarised spread spectrum mobile radio systems. Normally SS make use of large number of frequency hopped symbols which results in minimum mutual interference. The receiver should always synchronize with the code to recover the data which ensures multiple users to access the network at the same time. There are three specific ways in spreading the bandwidth namely frequency hopping, time hopping and direct sequence (Prasad and Hara, 1996).

The PN sequence must hold the following properties (Yang and Hanzo, 2003):

- Deterministic and random
- The cross-correlation between any two PN codes must be very small
- The PN code must have a long time period

The narrow band data in CDMA is multiplied by a large bandwidth signal usually a pseudo random noise code (PN code) (Wu *et al.*, 2010b). All users in a CDMA system (Fig. 3) transmit simultaneously making use of the same frequency band. By correlating the received signal with the same PN code used at the transmitter, the original data is recovered (Arnstein, 1979). PN sequence has a chip rate higher then the data bit rate. PN code is a sequence of ones and zeros normally referred as chips which alternates in a random fashion. Mingxin *et al.* (2008) proposes scrambling codes using PN sequences provides excellent autocorrelation and cross correlation properties. The modulation is performed by modulo 2 addition of data with PN sequence. Since each user retains their permanent unique code, there is no need for channel switching or address changing (Viterbi, 1985) as the user moves from cell to cell the desired signal is then filtered by removing the wide spread interference and noise signals. The interference limit of the CDMA system is always limited by the tolerated total interference (Malarkkan and Ravichandran, 2006). CDMA systems using QPSK modulation was studied and simulated by Guo *et al.* (2010). The effect of multipath fading on high data rate transmission will be combated by spread spectrum techniques was proposed by Turin (1980).

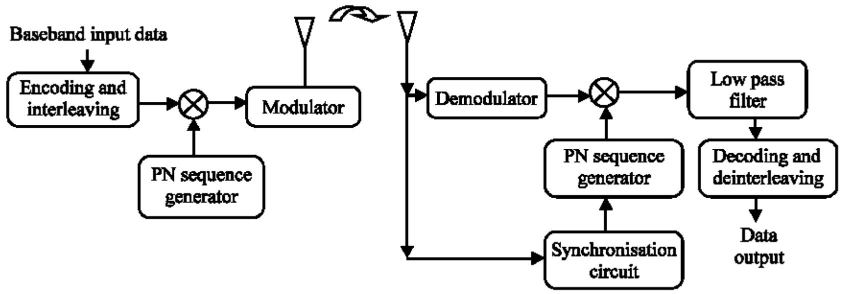

Fig. 3: CDMA system

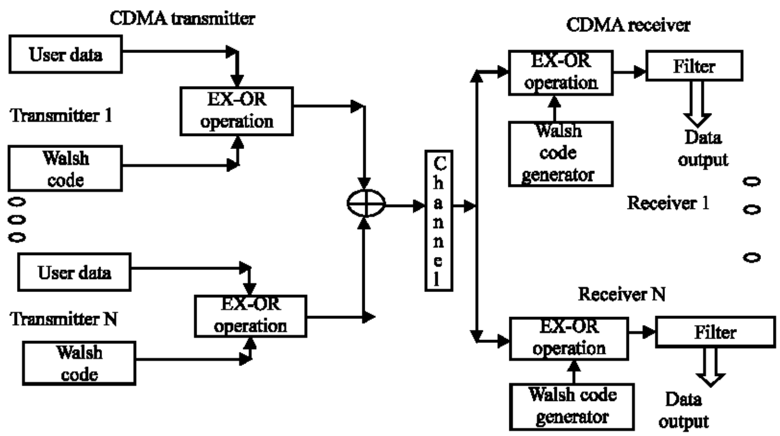

Fig. 4: CDMA transmission and reception

Properties that made CDMA system more secured and work in presence of jamming:

- Multipath tolerant
- Multiple access
- Non interference and interference rejection (Sivakumar *et al.*, 2006)
- Anti jamming
- Ranging accuracy
- Diversity in multipath fading channels (Sourour and Nakagawa, 1996)
- Frequency reuse
- Implementation cost is low
- Robust to channel conditions
- Built-in addressing and security

The main disadvantage with SS system is power control due to the near far problem (Kavehrad and McLane, 1987). The performance evaluation of any transmission system is studied and verified based on the Bit Error Rate (BER) and Signal to Noise Ratio (SNR). SS systems always aims at maximum BER (Bingham, 1990).

Steps in CDMA transmission and reception (Fig. 4):

- Initially a PN code is generated and EX-ored with user data for each transmitter
- The input data modulates and spreads the PN code

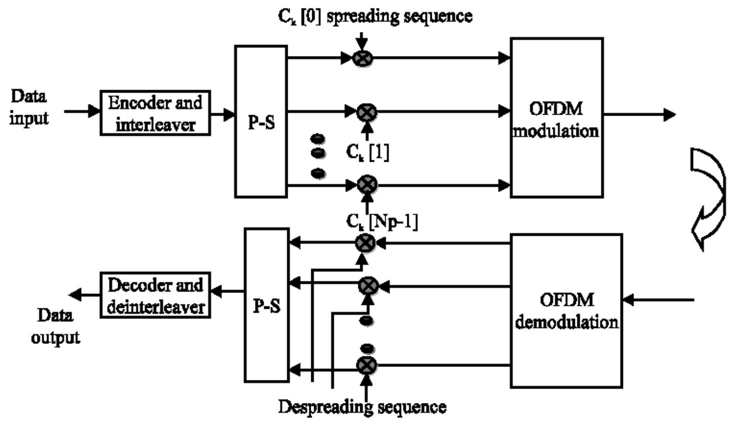

Fig. 5: MC-CDMA system model

- The spreaded signal modulates the carrier (Hara and Prasad, 1996)
- Then it is amplified and passed through the channel for broadcasting
- At the receiver the received carrier is amplified
- Then it is mixed with a local carrier to recover the spreaded data
- Receiver receives the correct code
- The received signal is correlated with the code generated and the information is extracted

Process gain of CDMA: By the spreading and despreading process the gain or signal to noise improvement is referred to as process gain (Kennedy, 1982). It is the ratio of spread spectrum bandwidth to the original data bit rate:

$$\text{Process gain} = \frac{\text{RF bandwidth}}{\text{Information bandwidth}}$$

RF bandwidth refers to the transmitted bandwidth after spreading the data and information bandwidth is the bandwidth of the information (Alper and Arnbak, 1980). Direct sequence CDMA uses rake receivers which applies spreading sequences in time domain. High chip rate, high clock rate and high power consumptions are required to reduce the multipath fading (Lionti *et al.*, 2001).

To overcome these impairments CDMA is combined with Multi carrier modulation called OFDM to produce MC-CDMA. Radio channel is usually time invariant and frequency selective. In spread spectrum transmission, signal occupies an excess bandwidth than the required one and spreading is accomplished by a code independent of the input (Pickholtz *et al.*, 1982, 1984, 1991).

Multi carrier (MC)-code division multiple access (CDMA): MC-CDMA that combines Multi Carrier (MC) and Code Division Multiple Access (CDMA) deals with frequency-selective fading (Sourour and Nakagawa, 1996; Hartmann *et al.*, 2003) providing multiple-access facility. In MC-CDMA, normally a symbol is spread into multiple spreading sequences. Then each spreaded sequence is transmitted over a subchannel and be distributed along the time or frequency (Hara and Prasad, 1996). Multiple users transmit at the same time and frequency and the symbols from each user are detected by using the difference of spreading codes for different users McCormick and Al-Susa (2002) and Yang and Hanzo (2003). MC-CDMA system model is presented in Fig. 5.

Combination of CDMA schemes and OFDM signalling can be called as spreading assisted OFDM (Chouly *et al*., 1993). In MC-CDMA system spreading sequences are applied in frequency domain rather than in time domain. This maps different spreading codes to the OFDM subcarriers (Hara and Prasad, 1997). Hence, each OFDM subcarrier has a data rate identical to the original input data rate and the multicarrier system has an increased rate due to spreading in a wider frequency band (Kondo and Milstein, 1995). Spreading sequences are applied to each OFDM subcarrier which has a data rate identical to the input rate (Wang and Giannakis, 2000). The spreading chips are applied to the serial to parallel converter and IFFT is imposed on these parallel data. Spreading sequences are orthogonal to each other which separate the desired signal from other users. Walsh codes and Gold codes are the well known orthogonal codes (DaSilva and Sousa, 1993) which provides zero correlation and is best suited for MC-CDMA systems.

The MC-CDMA transmitter spreads the original data stream over øÛh subcarriers using a given spreading code of Ck [0], Ck [1], Ck [2],……..Ck [Np-1] 19ê in the frequency domain. By spreading each data bit across all of the øÛh subcarriers the fading effects of multipath channels is mitigated.

The Kth MC-CDMA user's transmitted signal is given by:

$$s_k(t)=\sqrt{\frac{2p}{N_p}}\sum_{n=0}^{N-1} b_k(t)c_k(n)\cos(2\Pi f_n t) \tag{2}$$

b_k (t) represents the binary data of the k^{th} user.

Ts is the symbol duration, Δ is the minimum spacing between two adjacent subcarriers where Δ = 1/Ts:

$$\text{Ck [0], Ck [1], Ck [2],…….Ck [Np-1] be the spreading sequences} \tag{3}$$

Ts represents the symbol duration.

f_n denotes the subcarrier frequencies where, n = 0, 1, 2 …… Np-1 where, Np denotes the subcarriers. P be the transmitted power.

In MC-CDMA, spreading sequences are orthogonal and hence separates the desired signal from other users (McCormick and Al-Susa, 2002). High speed operations are required at the output of the spreader in order to carry out the chip-related operations. At the receiver end, the corresponding chip sequence is recovered using FFT after sampling at a rate of N/T samples/sec and the recovered chip sequence is correlated with the desired user's spreading code in order to recover the original binary information.

The aim of MC-CDMA is to support high data rate services and frequency diversity in remote wireless environments and also prevents the annihilation of certain subcarriers by deep fades. This is achieved by spreading each subcarrier's signal with a spreading code and thereby increasing the achievable error-resilience, since corrupting a few chips of a spreading code the subcarrier signal may still be recovered. MC-CDMA provides better multiple access which reduces multiple access interference and intersymbol interference which improves the bit error rate (Venkatesan and Ravichandran, 2007).

One of the main disadvantages with OFDM based Multicarrier CDMA systems is the Peak to Average Power Ratio (PAPR) of the transmitted signal. Whenever, the peak transmitted power is limited by implementation Constraints, it reduces the average power of the transmitter and limits the range of transmissions. Multicarrier signal exhibits a high amplitude variation subjected to nonlinear distortions resulting in out-of-band emissions and co-channel interference causing a significant degradation in the system's performance.

SPREAD SPECTRUM AND STEGANOGRAPHY (SSS)

Since early 1990's researchers and industries concentrates on Cryptography (Schneier, 2007) and there has been a rapid interest in Steganography since the late 90's (Cheddad *et al*., 2010). It concentrates on embedding secret message in a cover message associated with a key to produce stego image (Stefan and Fabin, 2000; Rabah, 2004). The cover can be a Plaintext, Still image (Janakiraman *et al*., 2012; Hmood *et al*., 2010; Amirtharajan and Balaguru, 2009; Padmaa *et al*., 2011), Audio (Ahmed *et al*., 2010) or Video (Al-Frajat *et al*., 2010). In today's communication broadcasting industries and publishing media's are interested in information hiding (Bender *et al*., 1996), copyright marks in books, digital films, multimedia and audio recordings. It also includes automatic monitoring of radio advertisements, medical safety by using Digital Imaging and Communications in Medicine (DICOM) which is a standard for handling, printing and storing information about the doctor and the patient in medical imaging ensuring safety (Anderson and Petitcolas, 1998) and for telemedicine application (Thenmozhi and Prithiviraj, 2008). Due to the rapid growth of multimedia communications high data rate and protection against data piracy is required. OFDM ensures high data rate and Steganography takes care of embedding additional confidential information in it. Cox *et al*. (1997) and Xie *et al*. (2007) proposed a secured Spread Spectrum (SS) based watermarking for multimedia images which provides robustness to compression, filtering and digital to analog conversions.

Here, a message is embedded in the digital image by the encoder (Stefan and Fabin, 2000) which utilizes a key results in stego-image. Then it is transmitted over a channel. At the receiver it is processed by the decoder using the same key used for transmission to provide the message output. Classification of information hiding is presented by Petitcolas *et al*. (1999) in their review paper as covert channel, steganography, anonymity and watermarking. Even though this paper intention has to give an overview about stego implementation in spread spectrum for more clarity, a simple discrimination among three has been given in Table 2. A simple classification in steganography is spatial domain method (Thanikaiselvan *et al*., 2011b) and transforms domain method (Thanikaiselvan *et al*., 2011a). General block diagram of stego system is presented in Fig. 6.

Banoci *et al*. (2009) proposed a codebook based secret data embedding in CDMA system. Banoci *et al*. (2010) extended their work by making use of error control codes in CDMA systems. Another CDMA based embedding has been analysed by Amirtharajan and Balaguru (2011) where they divide the secret message in to four parts and then embed it in the four quadrants of the cover.

Table 2: Discrimination between cryptography, steganography and water marking

Cryptography	Steganography	Water marking
Secret by scrambling	Covered hidden writing	Embedding copyright details into the digital content
Scrambles the content of the message	Hides both the contents and their existence	Hides both the contents and their existence, sometimes visible but it's hard to remove (roubstness)

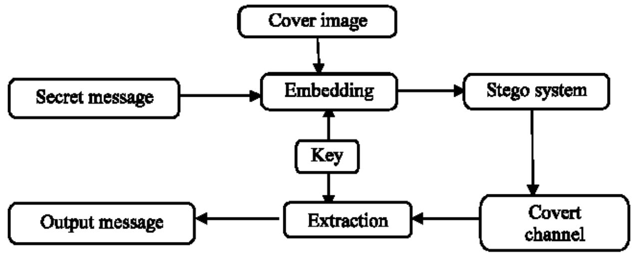

Fig. 6: General block diagram of stego system

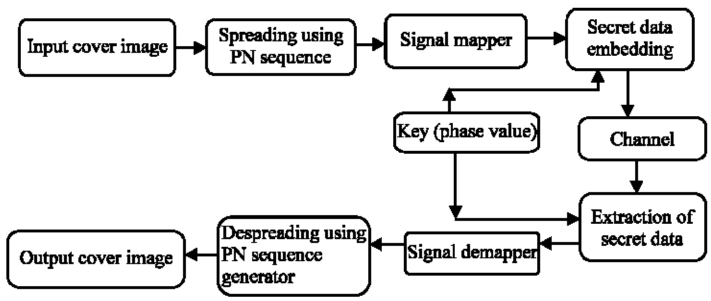

Fig. 7: Spread spectrum based image steganography

Table 3: Constellation table for BPSK

				IPCAE			QPCAE	
Symbol	Bit	Expression	IPCBE	0	1	QPCBE	0	1
D1	0	$\sqrt{\frac{E_S}{T}}\cos(2\pi f_c t+0)$	1	1	1	0	0.2	-0.2
D2	1	$\sqrt{\frac{E_S}{T}}\cos(2\pi f_c t+\pi)$	-1	-1	-1	0	0.2	-0.2

IPCBE: In-phase component before embedding, IPCAE: In-phase component after embedding, QPCBE: Quadrature phase component before embedding, QPCAE: Quadrature phase component after embedding

In this study we concentrate on Spread Spectrum Image Steganography (SSIS) introduced by Marvel *et al.* (1998) which embeds a secret message on a digital image. The embedded secret data can be retrieved with the help of keys. Lin *et al.* (2006) proposes a new embedding scheme in which data's are embedded in the physical layer of OFDM networks and extended in Kumar *et al.* (2011). Tie-sheng *et al.* (2008) presented a Quantization Index Modulation (QIM) in OFDM networks where embedding of the secret data is done by selecting the quantizer based on space domain which operates on gray scale images of 0 to 255 levels to represent the pixels.

Embedding the secret information can also be done at the signal mapper block utilizing BPSK/QPSK /QAM as shown in Fig. 7. Here embedding is done making use of BPSK technique and the constellation and phasor diagrams and their related equations are presented in (Fig. 8, 9, Table 3).

BPSK before embedding:

$$\Phi = \begin{cases} 0 \ \text{if} \ \ m=0 \ \ 0 \ \text{if} \ \ m=0 \\ 1 \ \text{if} \ \ m=1 \ \ \pi \ \text{if} \ \ m=1 \end{cases} \quad (4)$$

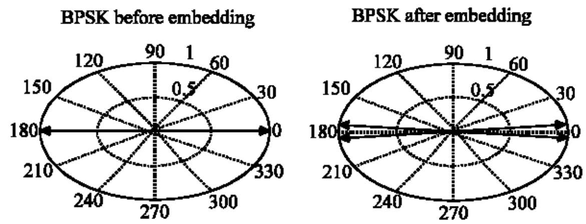

Fig. 8: Phasor diagrams, where embedding is done in signal mapper using BPSK modulation scheme

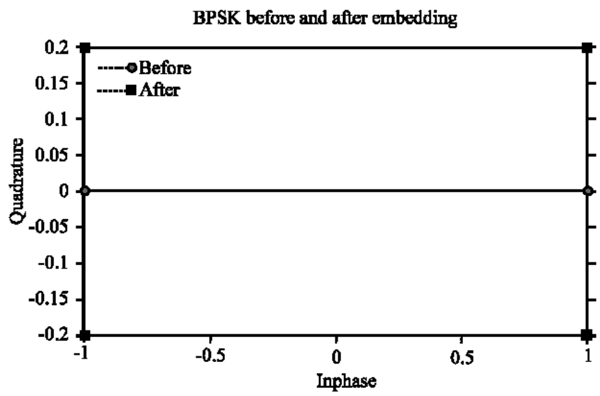

Fig. 9: Constellation diagram where embedding is done in signal mapper using BPSK modulation scheme

BPSK after embedding:

$$\Phi = \begin{cases} \dfrac{0.25\pi}{8} \text{ if } m=0 \ w=0 \\ \dfrac{15.75\pi}{8} \text{ if } m=0 \ w=1 \\ \dfrac{8.25\pi}{8} \text{ if } m=0 \ w=0 \\ \dfrac{7.75\pi}{8} \text{ if } m=1 \ w=1 \end{cases} \tag{5}$$

Classification on SSS and its future trend: The future trend on spread spectrum steganography is outlined in Fig. 10.

The confidential information could be embedded in any one of the following ways:

- Source coding
- Compression
- Signal mapper
- Channel coding
- Puncture coding
- Chaotic sequences

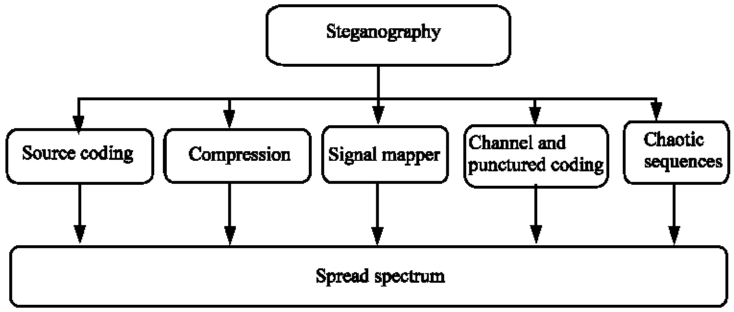

Fig. 10: Classification of spread spectrum steganography (SSS)

The first two always offers good cryptic effect and the later four are really useful for covert communication.

CONCLUSION

Wireless communication must cope up with performance limiting challenges such as frequency selective fading and ISI for high data rate transmission. OFDM as a multicarrier modulation technique is effective for supporting high speed transmission as well as combating multipath fading and frequency selective fading in broad band wireless communication. This review presents, basic OFDM System implementation, CDMA and MC-CDMA. Later, how steganography could be used to send additional confidential information using signal mapper and other possible ways are discussed in detail.

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