

Wavelet Based Alternative Modulation Scheme Provides Better Reception with Fewer Errors and Good Security in Wireless Communication

Ramachadran Hariprakash
Arulmigu Meenakshi Amman
College of Engineering,
Tamilnadu, India
rhp_27@ieee.org

Raju Balaji
Instrumentation Dept,
University of Madras
Tamilnadu, India
balajicisl@yahoo.com

Sabapathy Ananthi
Instrumentation Dept
University of Madras
Tamilnadu, India
ananthibabu@yahoo.com

Krishnaswami Padmanabhan
Anna University
Chennai
Tamilnadu, India
ck_padmanabhan@rediff.com

Abstract - In this paper, a different scheme of encoding digital data using wavelet functions instead of sinusoidal waves is explained. Data communications use various modes of encoding the data bits into a frequency signal. Phase shift keying of various forms such as Binary Phase Shift Keying, Quaternary Phase Shift Keying, etc., are in vogue in several current communication schemes, such as Global system for mobile communication. Errors in bits at the received end through a wireless channel are common in such data communication. These errors are mainly caused by improper phase changes in the detected audio signal. Since the method presented here with the use of wavelet functions provides several clues for identification of the data symbol instead of just by one criterion viz., the phase of the carrier as in the Phase shift keying schemes, this method is found to be better in performance. Simulation of the scheme was made with Matlab and the results provide an improved bit error ratio. Also, by varying the wavelets as per the user's choice, provides a higher level of security.

Keywords - Data encoding; PSK Modem; Wavelet functions; Daubechie Wavelet; Bit Error Rate.

I. INTRODUCTION

Data communication has been employing several modes of encoding the data bits into an analog signal. Phase shift keying (PSK), in its various forms, such as Binary PSK, Quaternary Phase Shift Keying (QPSK), etc., use a baseband sine waveform with different phase positions to encode the data bits[1]. So far, alternatives to the sine wave signal for modulation have not been considered in any existing communication scheme, wired or wireless. All of the current methods employ a combination of phase shifting and amplitude changes for encoding the data bits. For example, in Figure 1, the QPSK modulation method uses four phases of the sine wave, with 90° phase difference between symbols. In phase notation, the four waves can be represented as $0.7+0.7j$, $0.7-0.7j$, $-0.7+0.7j$, and $-0.7-0.7j$ (Fig.2).

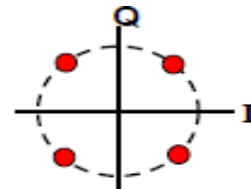


Fig. 2. The phase plot of QPSK symbols are having values in the complex plane marked.

When symbols of various values are thus encoded as analog sine modulation signals, we get a problem of spectral leakage, since there are discontinuities from symbol to symbol waveforms. This introduces errors in the case of transmission with multiple carriers. For instance, a truncated sine wave for symbol 01 will have a spectrum which spreads and is not confined to a single point. The shape of the spectrum will be somewhat similar, as shown in Figure 3.

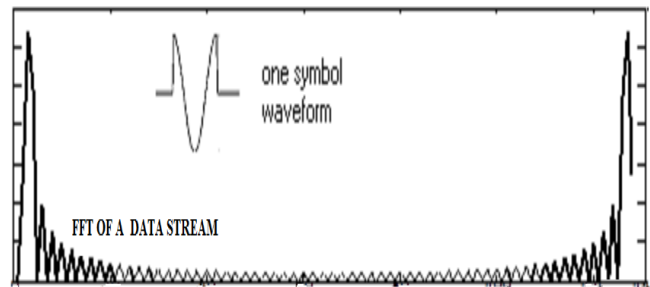


Fig. 3. The Fourier Transform (absolute value) of a data stream in a plain QPSK encoding modulating method is shown.

An alternative modulation scheme using waveforms of standard wavelet functions of the Daubechie (DB) type is shown in Figure 1. These functions are mathematically well defined and possess properties suitable for encoding and decoding. Four such wavelets, the DB4, DB6, DB8 and DB10 are shown as used for the same four symbols of data (00, 01, 10, and 11).

Trying such alternative modulation is done with a view to provide fewer errors in reception and also with some security provisions. This is done by using wavelets assigned to the bit patterns that can be of user centric.

Amongst the different wavelets known, such as Meyer [5], Coiflet [5], etc., the Daubechie wavelet [5], alone have several waveforms available for its different K-values and thus, it enables encoding more bit patterns per symbol.

To understand the genesis and properties of Daubechie wavelets, one can refer Addison [2]. During the symbol time, the end points of the waveform reach zero level and there is no discontinuity from symbol to symbol. This

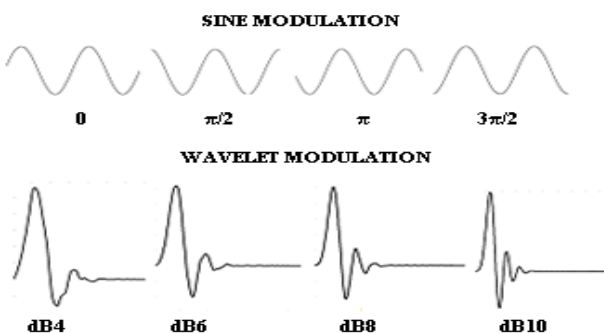


Fig. 1. Comparison between existing sine wave QPSK modulation and proposed wavelet modulation.

helps in having a spectrum without any leakage. Well defined spectra result for such waveforms. So, in multiple carrier modulation methods as used in 802.11 and related schemes, the method can be applied with definitely much better results.

To point out the lacuna in an existing 802.11 multi carrier scheme, consider how the time signal is formed in that method, as clearly depicted in Figure 4. In this figure, for simplicity, five subcarriers are shown. Each subcarrier can have a particular phase angle of a few cycles of the sine wave used for modulation and this is represented as a phase with a real part and an imaginary part, as shown in the spectral representation as I and Q.

Each carrier is at a frequency range which is twice, thrice etc. of the first carrier. In order to generate the total time signal, which will include all the carrier frequencies, from the low to the highest, in it, the present method just *assumes* that the symbol waveform can be represented as a phase of single value, such as $0.707+0.707j$ for one such QPSK symbol. From Figure 3, we note that is incorrect, because of the discontinuous nature of the segment of a QPSK signal. In Global System for Mobile Communication (GSM), a Gaussian filter is applied to the symbol waveform called Gaussian minimum shift keying. Even still, there are discontinuities between symbols in the signal in time domain.

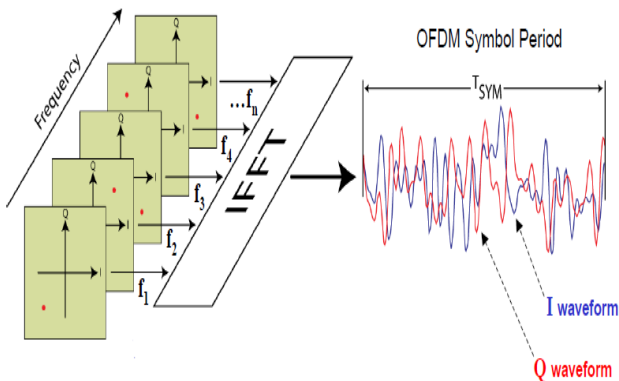


Fig. 4. The present method of forming a time signal for RF modulation in a Multi-carrier baseband scheme [3].

The mistake committed in the present scheme for getting the time signal from multiple QPSK (or even higher density schemes like 16QAM, 64QAM, etc.) lies in assuming that the spectrum of each carrier is a single point phase. Only if the sine wave is continuous for all time, the Fourier spectrum will be a single phase. So, combining these single phases at f_1, f_2, f_3, \dots etc. through an inverse Fourier Transform (FT) to generate the total time slot signal is having spectral leakage errors. These spectral leakage errors can definitely contribute to inter-symbol interference while decoding the signal at the received end.

The rest of the paper is arranged as follows. Section II gives a comparison of errors for standard QPSK and wavelet modulation. Section III deals with the bit error estimates for the proposed method. Then, the following Sections IV and V deal with wavelet shift keying multi-carrier communication as compared to sine phase shift modulation. The test implementation is discussed in

Section VI and the comparison with sine modulation is detailed in Section VII. Section VIII deals with other attempts [12] bearing the name wavelets [13][14] and finally, the paper ends with a conclusion section.

II. ERRORS IN SYMBOLS – A COMPARISON

The process of decoding a standard sine modulated (QPSK, 16 QAM) signal first requires the generation of the reference sine wave from the first few data symbols, which are the initialization symbols. A Costas loop is a technique [4] that is also used to generate this reference wave. If the reference signal is slightly out of phase, that gives errors throughout the data.

Then, a multiplication of the signal received with this reference is performed. The average of this product is proportional to the cosine of the phase difference between the reference and the received segment of the phase shifted sine wave in that time slot. For each time slot, the phase is thus obtained. From this phase, the data symbol is decoded. With additional amplitude modulation as in QAM mode, the amplitude of the signal is also used to determine the symbol value.

In other words, the only information used for decoding is the phase of the signal. Phase of a sine wave is often subject to delays and changes en-route that is the reason for the errors in the received data.

Let us now describe the decoding method when wavelet signals are used. A wavelet signal is a well defined mathematical signal, which has a compact support and a finite spectrum without spreading like the phase shifted sine wave segments. The pattern of each of the Daubechie signals is different and specific [5]. Thus, there are several criteria available for determining, in any one time slot, which wavelet is received.

First of all, from the received data, which is converted into digital numbers from the analog to digital convertor in the receiver, we have to isolate the symbols. This is the process of synchronization. In this case, it is much easier than for sine phase modulated signals. The first few data symbols are known and are identical. The first peak and then the peak of the second symbol are fetched. The midpoint of data is a starting point for the second symbol. We know the number of data points in a symbol from the two peak positions. From then on, the data samples can be isolated easily.

The wavelet functions possess several peaks. The following criteria for decoding have been used by the authors.

i). RMS value of the autocorrelation function:

This calculation resembles the calculation made in the sine modulation existing methods. Correlation is multiplication, shifting and addition, and the estimation of the Root Mean Square (RMS) value.

ii). Peaks their ratios and spacing is another criterion:

Among the DB4 to DB20 wavelets, the peaks differ. The number of peaks increases for the higher degree wavelets. To determine the peaks is a simple calculation. By comparing with the values of the received data in each time slot, the correct symbol value is found.

A check on the results of the above two methods is able to infer plausible symbol errors.

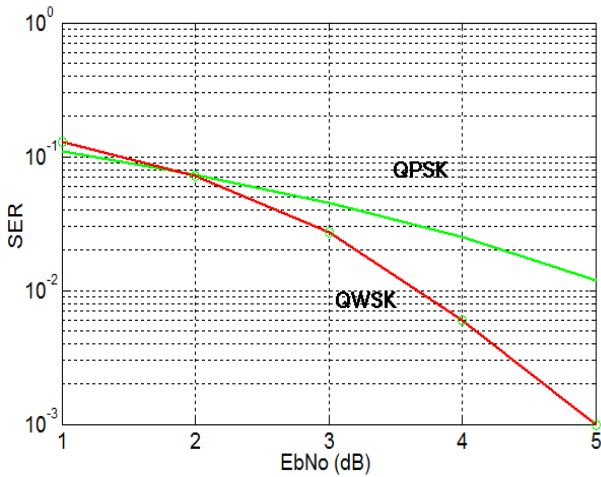


Fig. 5. Errors simulated by Monte Carlo simulation for the QPSK and our wavelet modulation schemes for different signal to noise ratios.

We conducted the tests with 16 wavelets representing a four bit data symbol and obtained good results.

For example, the Matlab sample demo program for QPSK [6] sine phase shift modulation scheme gives error rates more than our 4 bit wavelet based keying method, as shown in the graph of Figure 5. We note the good reduction in errors with the method.

III. BIT ERROR ESTIMATE COMPARED TO PLAIN QPSK

In sine modulated QPSK transmission, the bit error is estimated as the probability of finding the phase position correctly. This is based on the conditional probabilities of two vector positions [7], i.e., the two axes of the phase. The probability of error per symbol is denoted by P_e and is given by

$$P_e = \text{erfc}(\sqrt{E/N_0}) \quad (1)$$

Where a white Gaussian noise (variance $N_0/2$) is assumed to affect the transmitted signal. This result was obtained by integrating up to infinity, since the vector can take a position all along the axis of the phase. Such a result has also been verified by Matlab's simulations using the Monte Carlo method [6].

In this WSK method, the probability of getting a wrong wavelet symbol instead of the correct symbol at any instant depends on the probability of nearness to the right symbol. The root mean square criterion of the autocorrelation function of the received symbol has the values, which decrease from DB4 to DB32, monotonically. These values are stored by *a priori* calculations.

The probability of the value deviating far from the right symbol's value depends on the noise. The integral of the probability function of this Gaussian random variable is a definite integral between the two fixed values only and not from 0 to infinity as in the derivation of the QPSK bit error probability.

TABLE I. COMPARISON TABLE BETWEEN 16 QAM AND 16 WSK

	<i>Symbol synchronization</i>	<i>Detecting the Symbol</i>	<i>Symbol assignment</i>	<i>Bit Errors by Simulation</i>
16 QAM	Synchronization requires generating a reference sine wave, which is difficult and if there are slight errors in the reference, that will reflect all data bits.	This symbol detection is based on both amplitude and phase position of the sine waves within the time slot. With very few cycles sent in each slot, the phase detection is often erroneous due to the analog signal variations at the edges of the symbols.	Symbols are assigned values so that nearby constellation points (in phase diagram) differ only in one bit value. That constrains the values of the symbols with respect to the phase shift values.	By a simulation it is possible to send around 10000 symbols randomly and add Gaussian White noise of a definite Signal to noise ratio. Then by decoding, the data can be compared and symbol errors counted. The error rate is higher than for the WSK method.
16 WSK	Synchronization is easy after finding the first two data symbol's peak position and from then on, based on fixed time sampled allotted to each symbol.	Here, the detection is based on more than one criterion. The first and best criterion is (1) above. By using more criterion and comparison, confidence levels of symbols can also be found.	Here, there is no constraint on bit values & encoding wavelet numbers. We can shuffle the values of wavelet nos. with respect to the symbol values, which can be used for encryption.	Simulation similarly by a large number of data symbols encoded, noise added and decoded gave better results.

Thus, the value is definitely less than in the case of the sine modulated method. The errors stimulated by Matlab for Monte-Carlo simulation for QPSK and the wavelet modulation scheme is shown in Figure 5. Table I above shows the comparison table regarding the features like the symbol synchronization, detection of symbol, etc., between the 16QAM and 16WSK.

IV. PROPOSED WAVELET BASED SCHEME SIMILAR TO OFDM IN SINE PHASE SHIFT MODULATION

In the 802.11 a-g WLAN example, there are 48 subcarriers. The symbol time is 4 μ s. The carrier spacing is 312.5 KHz [8].

Similar to this, if we want to implement the wavelet based keying scheme, let us examine the details of its implementation in what follows. For each time slot, there are many subcarriers with a spacing of frequency between them. We have to generate the time signal for all such

carriers put together. As the example from Figure 6a shows, addition of a second carrier with a DB8 waveform to the first carrier will mean adding a shifted version of the spectrum of the DB8 signal to the total spectrum. Thus, there are two spectral peaks shown for two carriers numbered 1 and 2 in Figure 6a. The time signal for this will be as in Figure 6b. This is obtained by the inverse Fourier transform.

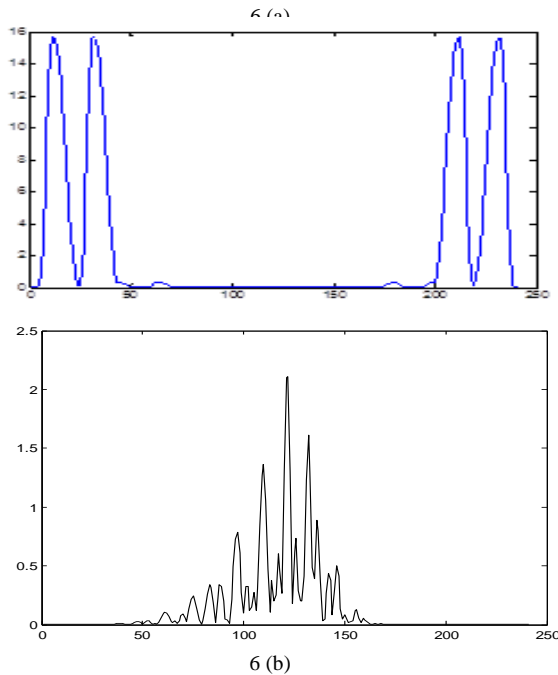


Fig. 6 (a). An addition of a second sub carrier as a second spectrum added with a shift of frequency of 1/8 of the sampling frequency.
 Fig. 6(b). The time signal obtained by using the above two sub carrier modulations. Only 2 subcarriers are shown for clarity.

For example, let us take for simplicity an eight carrier system. There will be eight symbols sent in one time slot. These eight symbols will be formed by the data at the current time slot. Let the data for these 8 carriers are, say, DB4, DB8, DB12 DB20. We have pre-calculated spectra for each of the several encoding wavelets. We just position these spectra at the frequency slots 1 to 8 in this order. For Figure 6a, it was done for just two carriers. For three carriers, Figure 7a illustrates the signals for each of the carriers. The process of positioning the spectra peaks and arriving at the overall spectrum at any one time slot is a simple operation. The Inverse Fast Fourier Transform (IFFT) of the total set of such spectrum will give the total time signal.

The points in the Inverse Discrete Wavelet Transform (IDWT) will be just the product of the number of subcarriers and the number of data points in one symbol. In Figure 7, 128 point IFFT space is chosen. This gives 64 points upto the folding frequency. If 8 subcarriers are used, each subcarrier space is 8 points in the total of 64, being half the total IFFT space. When combining the data for each subcarrier, we have to shift the spectrum of the corresponding wavelet for its symbol. Thus, the positioning of the pre-stored spectra for all the 16 wavelets (in a scheme similar to 16QAM) can be done to

form the spectrum of the total time signal. This is inverted and it is a 128 point IFFT. This signal is modulated with the RF and transmitted.

Instead of this complicated method involving time for IFFT calculation, the following method is adopted here.

We know the wavelets used for encoding and also the subcarrier frequencies. The received RF demodulated signal would be a time signal comprising of all these wavelets. To retrieve each of the subcarrier data, we do an FFT of that signal. That FFT signal has to be separated into 8 different spectra by splitting the same. That requires a splitting program. Each of the split spectra is inverted to yield the DB waveforms for each subcarrier symbol. The illustration in Fig. 7b shows how the waveforms for three subcarriers merge very well with the original waveforms for the symbol. Thus, the symbols could be retrieved from all the subcarriers.

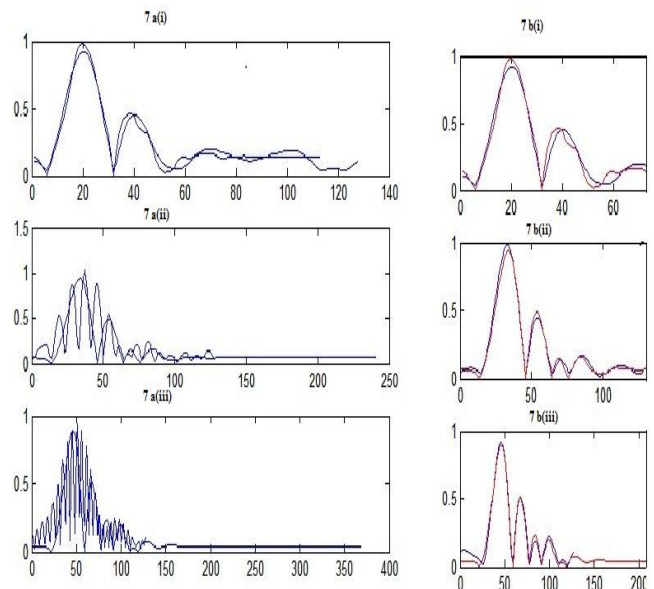


Fig. 7 a i). The DB4 signal in the first time slot, superimposed with the signal created by a truncated IFFT. 7a ii) The DB8 signal if it is shifted one subcarrier right then shows higher frequency waves in it after the IFFT. 7a iii) The DB12 signal shifted two subcarriers right then it indicates still higher frequencies.

Fig.7 b (i), 7b(ii), 7b(iii) Shows the respective received signal after frequency separation, the received data merges with the symbol data perfectly.

The above Figure 7 just illustrates the method, though, in practice, the data is actually collected from more subcarriers and then decoded. The above simulation is just to illustrate that inter carrier interference is totally absent here. For sine modulation schemes, the OFDM simulation is found in [9].

V. MULTIPATH ERROR ESTIMATION

Whenever multiple carriers are used, multipath reception always leads to errors more than desirable. The estimate of multipath errors for a general sine modulated multicarrier signal is discussed elsewhere [10]. To make a comparison of the OFDM or QAM schemes with this proposed WSK scheme, let us examine the effect of a second path signal adding to the direct path. Let us assume that, as usual, the second path arrives at the next

time slot and hence, in the second timeslot, we have a reception of the combination of two symbol signals.

Let us compare the performance with respect to inter-symbol interference for the sine and wavelet based schemes.

i) Sine phase modulation method:

Let us consider that the second (longer) path signal is attenuated by about 50% to that of the directpath signal and that the phase of that symbol is likely to be any one of the constellation points in phase space. If the two phases are very adjacent ones, then the error in phase by combining the two path signals will be less than half the phase difference between these two phases. But, if the previous symbol is a far apart symbol in phase diagram, say 135° away from the current signal, then the addition of the two phases moves the net phase by as much as 45° out of correct position (see Fig.8).

ii) Wavelet based MWSK scheme:

In the proposed WSK method, the two symbols could be say DB8 and DB4 on the direct and secondary paths, which when added gives a composite signal. With a 50% of the latter signal which is a wrong signal, the net root mean square values of the two will be obtained by squaring and summing and again taking the root.

Thus, for example if 352 for DB4 and 115 for DB8 are used for this Fig.8, we get the net Fig. as

$$Rms = \sqrt{115^2 + (352/2)^2} = 210 \quad (2)$$

which is nearer to the DB8 and hence it still yields the correct data. It can be similarly shown in all cases, with even 50% indirect path signal, the correct results are obtainable, which is one of the merits of the proposed scheme. This compares favorably with the sine modulated scheme.

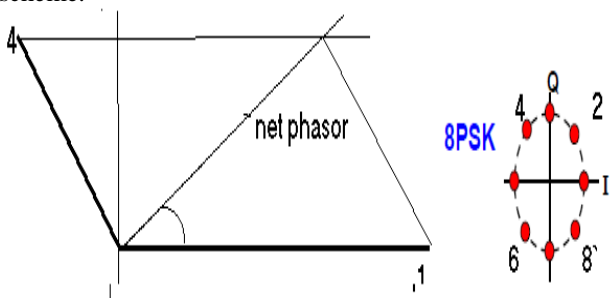


Fig. 8. In an 8 Phase Shift Keying sine modulation scheme, the path 2 signal belongs to no.4 and hence is at 135° to the horizontal.

The signal on the direct path is a no.1 signal, which is horizontal and is the true signal. Since the combination of even a 50% attenuated path 2 signals (note the inclined phase is half in length) would shift the net phase by 45° as shown by the parallelogram diagonal, the received symbol suffers an error. The comparison features of the proposed wavelet based scheme with sine based modulation scheme for multicarriers are given below in Table II.

TABLE II. COMPARISON TABLE BETWEEN SINE MODULATED O.F.D.M. AND WAVELET SIGNALS ON MULTICARRIERS

	<i>Formation of the total time signal in each time slot</i>	<i>Inter Carrier Symbol Interference</i>	<i>Multiple path and fading</i>	<i>Power levels</i>
OFDM (SINE)	This finds by table look up, the phase for each subcarrier's symbol based on the data. Then, it merges the phases in the frequency space as shown in Figure 4. Then, it generates the total time signal by an IFFT.	The spectrum of every subcarrier extends very much into the subcarrier previous and next to it. Because of the orthogonal property of sine waves, the multiplication with the correct subcarrier yields the phase value of the symbol. However, problems arise when waveforms are distorted or saturated. Wrong symbols are obtained.	Multiple radio frequency paths, such as reflections give added delayed signals to the receiver. These causes inter symbol interference. That is why, the method is not much usable for long distance wireless communication.	The power level in the modulation is sum of the subcarrier powers based on the RMS value of the sine wave voltage value used for modulation. The modulating power is more in this case than for the wavelet multicarrier.
MULTI CARRIER (WAVELET)	Here, we have samples of the several wavelets' signals are stored already in the different scales of frequencies. We just add the signals corresponding to each subcarrier's encoded wavelet.	In our method, there is no merging of the subcarrier frequency spectra as seen from Figure 6a. Thus, subcarrier signals are separable without any mixing. Hence, the performance is likely to be better.	Here, the addition of a reduced amplitude signal with delay from a reflected path will not affect the calculation involved in deciding the symbol. We have multiple criteria for decoding and hence the decoding is more definite and with plausible errors, confidence levels can be obtained by combining the results of the multiple decoding criteria.	The power level of the signal waveform from a wavelet used for encoding is less than that of a continuous sine wave. Thus, we have less modulating power in the scheme.

The method of combining the multiple subcarriers is through a look up table data, after encoding the symbols as wavelets for these multiple symbols.

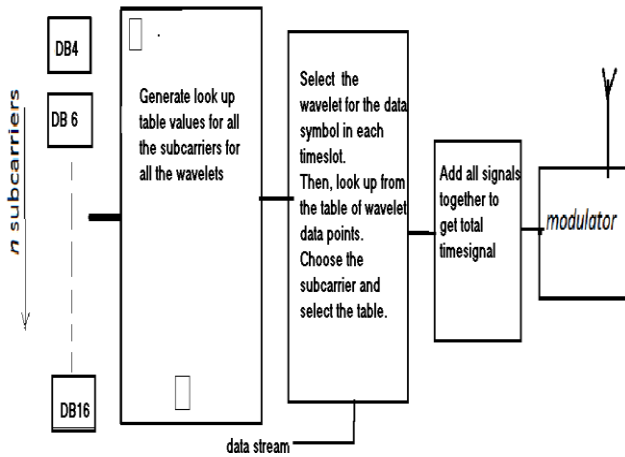


Fig. 9. Showing the scheme for multi carrier signal generation and modulation prior to transmission

The waveforms of the time signals are pre-stored and hence just addition of the waveforms will yield the composite waveform in time. This is shown in Figure 9, and is given to the RF Modulator.

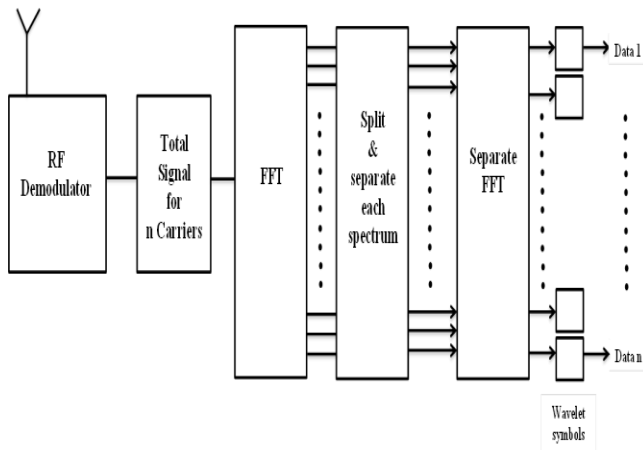


Fig. 10. Showing the method of decoding multiple carrier signals and separating the data symbols.

At the receiving end, the total demodulated time signal is transformed in Fourier space and the different symbol subcarriers are separated in this space. Each of them is inverse transformed to get back the wavelet waveform. By comparing the wavelet received with the encoding wavelets (Fig. 10), the symbol values are separately found.

VI. TEST IMPLEMENTATION

From the Matlab program, which generates the waveform of the time signal, we considered the transmission of the analog data through a RF signal generator with amplitude modulation facility. The signal is generated from the sound card of the computer using WINSOUND command on the Matlab. The sampling frequency is low, but is enough for testing; the sampling frequency value is 44.1 KHz. Therefore, we could send only 4 subcarriers $f_s = 44100$ and sound sc (signal, f_s) are the commands.

The signal from the sound card audio jack is connected to the modulator of the RF generator. The RF frequency is set to a radio frequency in the near short wave.

The receiver is tuned to this frequency, which is a communications receiver. The received data is again fed through the line input of the sound card of the PC. The PC reads the sound card audio using the command Analog input (AI) and other related win-sound commands. The audio signals are stored in user specified files. These signals are processed and the recognition of the wavelet is made, thus the data is created.

Digital data for wireless communication have to be converted to analog signals for modulation over a RF frequency for transmission. The method of encoding data bits has all along been using merely the phase shift and amplitude of a baseband (low frequency) sine wave. Alternative to the sine wave no other waveform has so far been tried out.

In our paper, we present the use of wavelets for modulation. We choose a particular type of wavelet for each data symbol (Table III). With 16 wavelet signals, we can encode four bits of data.

TABLE III. WAVELET SIGNALS AND THEIR ENCODING

S.No	Bits	Wavelet
1	0000	DB 4
2	0001	DB 5
3	0010	DB 6
4	0011	DB 7
5	0100	DB 8
6	0101	DB 9
7	0110	DB 10
8	0111	DB 11
9	1000	DB 12
10	1001	DB 13
11	1010	DB 14
12	1011	DB 15
13	1100	DB 16
14	1101	DB 17
15	1110	DB 18
16	1111	DB 19

The wavelet signals as sent through a typical transmission test look like in Figure 11. The typical waveform for a short stretch of eight symbols is shown as transmitted and after noise addition.

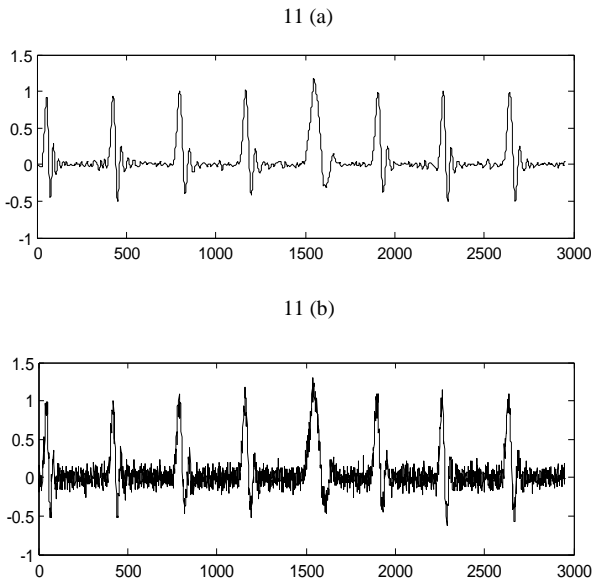


Fig. 11 a) Modulating wavelet signals for a set of 8 symbols. b) The addition of white noise is seen.

With multiple carriers in a single time slot, we can send multiple symbols resulting in greater throughput.

VII. COMPARISON WITH SINE MODULATION SCHEME

Thus, wavelet based modulation has been shown to provide a better symbol error and also reduces multi path distortion compared to the existing sine modulation method.

Secondly, we consider how a security aspect can be included in the scheme. For this, let us consider how the standard QAM modulation scheme encodes the data bit values.

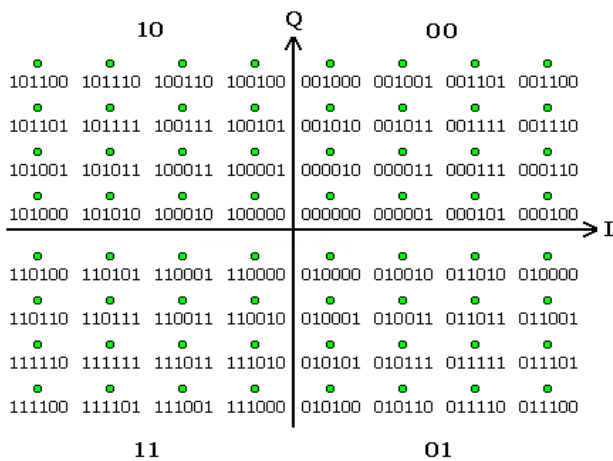


Fig. 12. Bit patterns used in the conventional 64QAM Modulation.

For example, the bit patterns versus the phase positions are indicated in Figure 12. It is noted that the data bit patterns have fixed positions in the constellation with a view to make only one bit change between adjacent phase points.

But, with our wavelet based functions, we have no such restriction. The wavelets assigned to the bit patterns can be the user's choice at any time and thus, by varying

the pattern versus wavelet function table from time to time, an additional level of security is obtained [11].

VIII. OTHER ATTEMPTS BEARING THE NAME WAVELETS

From Figure 5, it is noted that the signal in time course is evaluated by an IFFT at transmitter; the FFT is done at receiver. Looking at the transform pair (FFT-IFFT), some authors have thought of replacing this by other known transforms. Immediately it suggests the ubiquitous wavelet transform. The ordinary wavelet transform however reduces the number of points and so the wavelet packet transform comes to mind. This principle is like the analogy of traveler carrying cash from country to another. If he goes to Europe, he can carry Euros, pounds, dollars or even some material of value. But, other than the Euro, all the rest suffer losses in transfer. Thus, in the WPT imagination, the difference coefficients are always small in value compared to the approximation coefficients and the small values get easily masked by even a limited amount of noise. The reconstitution using the approximation and differences will yield considerably large errors. The authors propounding such methods could only treat their concept at theoretical and partial simulation level and not even a baseband actual transmit receiver session could be reported by them. In the proposed method, the multi carrier scheme uses merely the Fourier space and the time signals are normal. Only in the symbol level, we use the waveforms of the scaling functions of the DB wavelets. The scenario of our scheme is useful at single carrier for cellular communication and with multi carrier communication for short range wireless in-house and wired LAN.

Most literature cites the use of Daubechie wavelets for reasons already mentioned. The other wavelets may not provide for our use as much as sixteen different patterns for encoding. Hence, the proposed work rests mainly on the DB wavelet scaling function waveform modulation. So, comparing with other possible wavelets was felt unnecessary.

In the paper by Matthieu Gautier, Marylin Arndt and Joch Lienard [12], the signal is viewed as a sum of modulated wavelet packets. They suggest using the IWPT and WPT pair at transmitter and receptor. The concept is dealt with mathematically and so is their simulation. But, the details of an implementable scheme are left out in so far as actual waveforms for encoding a message is concerned and no techniques as to decode the signal at reception are given. The work [13] is also a very similar attempt. In another paper [14] it describes the possibility of the same WPT transforms for multicarrier communication by the similar WPT reception but they do not give of any decoding of neither symbols nor do they deal with how many bits are encoded in a symbol and in what manner the signal based on the DWT is generated. This paper is a conceptual account with more details of the wavelets filter functions and spectral overlaps of the multiple carriers. The bit error curves given are based only on their assumed theoretical Gaussian error formulas.

IX. CONCLUSION

Data communication in a security system, separately set up for a private or similar requirement, can exploit the advantage of such a different modulation scheme over conventional PSK based schemes. The encoding scheme method using 4, 8 or 16 wavelets in schemes with 2 bits, 3 bits, or 4 bits encoding in a symbol can be selected by the user and the assignment of bit patterns for the data symbol can also be the user's choice and can be varied from time to time to provide a level of security.

The usage scenario of the scheme can be anything, such as in-house, short range wireless or cellular wireless. The plain wavelet encoding without multiple subcarriers will suffice as is employed presently in wireless cellular systems. In short range wireless, as in 802.11 schemes, the multiple subcarrier wavelet schemes is applicable equally well as the present sine modulated scheme.

Additional bonus in the scheme is the better decoding possibilities leading to fewer errors, as seen in Figure 5, even in the case of basic QPSK versus 4-WSK scheme.

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