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Military Technical College, Kobry Elkobbah, Cairo, Egypt
Tel : +(202) 24025292 – 24036138, Fax: +(202) 22621908

Unequal Power Allocation of Image Transmission in OFDM Systems

M. M. Salah*, A. A. Elrahman**, A. Elmoghazy*

Abstract: The OFDM technique with cyclic time guard, which has been proposed for broadband communications, is an increasing approach to combat the frequency selectivity of the channel. In this paper, a modified OFDM scheme for image transmission is proposed. The new proposal is based on modification of the OFDM structure through using unequal power allocation for the successive OFDM symbols. Unequal cyclic time guard is also applied with unequal power allocation. The proposed method is compared with the conventional OFDM. Results show that the performance is improved at lower average cyclic extension periods and a lower average power when using the proposed method. The performance study of OFDM scheme is examined with and without forward error correction (FEC).

Keywords: OFDM, image transmission, and power allocation strategies.

I. Introduction

Future radio mobile communication systems that can provide diverse transmission services, such as video, voice, image and data, with high transmission rates and low transmited power are of much interest. The problem of transmitting high data rates over frequency selective fading channel is intersymbol interference, ISI ,which severely degrades the performance of the system. Multicarrier transmission in the form of orthogonal frequency division multiplexing (OFDM) [1,2] is a possible solution that can combat ISI effectively.
The OFDM technique has many advantages in wireless communications and is used in many practical systems. OFDM allows digital data to be efficiently and reliably transmitted in multipath environments by lowering of the symbol rate resulting in lowering of the Intersymbol Interference (ISI). In OFDM scheme; a single high-rate bit stream is converted to low-rate parallel bit streams. Parallel streams are modulated onto orthogonal sub-carriers. Spectrum of these sub-carriers are closely spaced and overlapped to achieve high bandwidth efficiency. The bandwidth of these sub-carriers becomes small compared with the coherence bandwidth of the channel; i.e. the individual sub-carriers experience only flat fading. So, OFDM transforms the frequency selective fading channel into multiple independent flat fading sub-channels. Therefore, an OFDM system can achieve a high data rate and a reliable transmission in a fading channel. OFDM also uses a cyclic guard time at the start of each symbol to remove any ISI shorter than its length.

* Egyptian Armed Forces
** Thebes Academy

In this paper, a study of combined use of convolutional coding and modified OFDM technique is presented. Based on this combination, an investigation of the effect of errors on different parts of the transmitted image and conclusions were drawn, based on the simulation results, that the bits at the beginning of each image frame are far more important than those near to the end of the frame because it stores general information about the image file. Thus if the bits at the beginning of each frame are better protected than other bits in the frame , better image quality could be achieved while minimizing the overhead due to forward error correction (FEC). So we propose in this paper a new Unequal Power Allocation (UPA) with Unequal Time Guard (UTG) in OFDM system. This scheme gives better image quality than the conventional error protection schemes with equal time guard and equal power allocation over frequency selective channels.

In this paper, exploiting the structure of image frames, a modification to the conventional OFDM scheme is done to enhance the performance of OFDM scheme with image transmission. A brief explanation of conventional OFDM scheme, model validation, and performance enhancement issues are also presented.
The paper is organized as follows; Section II provides some background on conventional OFDM scheme modeling and system validation, Section III presents the proposed strategy of unequal power allocation to enhance the performance and then apply this model to unequal time guard OFDM model that are proposed in [3] in Section IV. Section V concludes the paper.

II. Orthogonal Frequency Division Multiplex Modeling and Validation

A multicarrier communication system with orthogonal subcarriers is called an Orthogonal Frequency Division Multiplex (OFDM) system. In an OFDM system [2], the carrier spacing Δf is $1/NT$, where N is the number of the carriers and $1/T$ is the overall symbol rate. With this carrier spacing, the subchannels can maintain orthogonality, although the subchannels overlap. Therefore, there is no inter-subcarrier interference with ideal OFDM systems. The number of subcarriers N is chosen so that the subchannel bandwidth is less than the channel coherence bandwidth. Under this condition, each subchannel does not experience significant Inter-symbol Interference (ISI). The transmitted signal of an OFDM system for one OFDM symbol period is of following form:

$$s(t) = \mathrm{Re}\left\{\sum_n a_n \quad h(t)\exp\left(j2\pi f_n t + \phi\right)\right\} \qquad (1)$$

where a_n is the transmitted data symbol for the n-th subcarrier, $h(t)$ is the pulse shaping filter response, f_n is the n-th subcarrier frequency $fn = f_c + n\Delta f$.
As the number of OFDM subcarriers increases, the complexity of the modulator and demodulator is increased accordingly. However, the OFDM modulator and demodulator can be implemented easily by the use of inverse discrete Fourier transform (IDFT) and discrete Fourier transform (DFT) respectively. Figure 1 shows a block diagram of the OFDM transmitter. The time domain coefficients c_m can be computed by IDFT as:

$$c_m = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} a_n \ \exp\left(-j\frac{2\pi nm}{N}\right) \qquad (2)$$

where a_n is the input of the IDFT block which is the data symbol for n-th subcarrier, c_m is the m-th output of the IDFT block. After the IDFT operation, the parallel output of IDFT block c_m (m = 1, · · ·,N− 1) is converted to a serial data stream. From the IDFT operation of

Equation (2), the frequency domain data symbols are converted into a series of time domain samples. The digital samples are digital-to-analog converted, filtered and converted to a carrier frequency f_c.

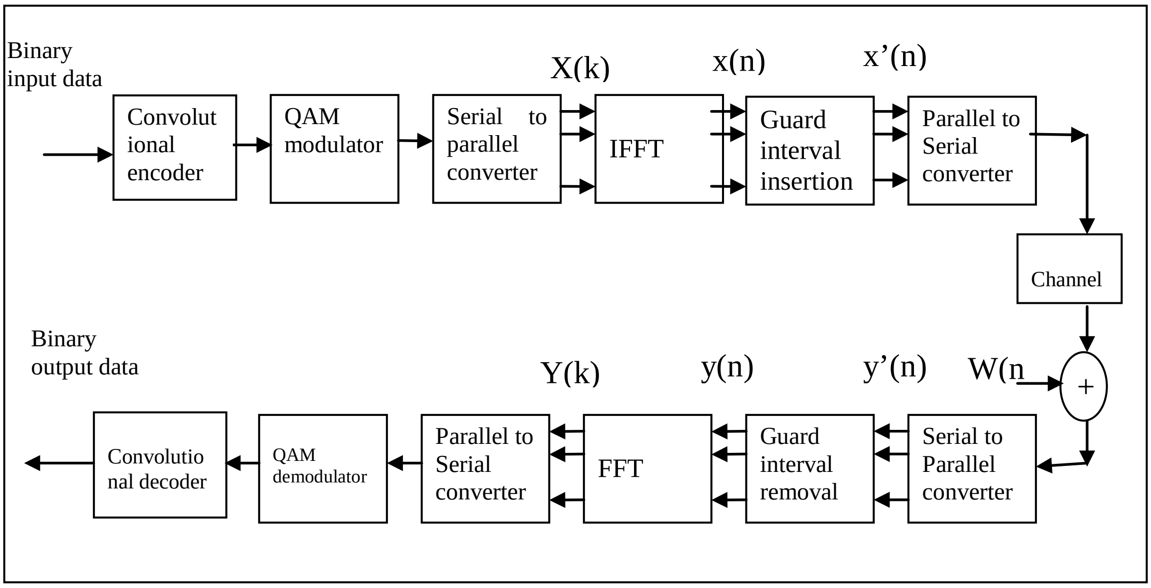


Figure (1) OFDM transmission and reception scheme.

At the receiver, the received signal is down converted to base band and sampled at the symbol rate *1/T*. Then, *N* serial samples are converted to parallel data and passed to a DFT which converts the time domain signal into parallel signals in the frequency domain. The OFDM system transmits the wideband data over many narrowband subchannels. The symbol duration of each subcarrier becomes $N\Delta t$, where Δt is the symbol duration of the input data symbols, assuming that each subchannel experiences flat-fading. In the time domain, a guard period is inserted between two OFDM symbols to prevent overlapping of two consecutive symbols by multipath delay spread. The guard period contains a copy of the end of the IDFT output and is called a cyclic prefix [2]. To decrease the SNR required to achieve the required quality of the received image, convolutional coding [4,5,6] is applied to the modified OFDM scheme. Coded OFDM is concatenation of OFDM scheme with the convolutional encoding.
Figure 1 illustrates the proposed system under study. As shown, Convolutional coding is integrated into the OFDM system to enhance the performance improvements in multipath fading channels [4, 8]. The binary input information is first encoded using convolution coding at a code rate *r*, and then OFDM modulation at transmission. On the receiver side, the OFDM signal is demodulated and decoded. The transmitted signal *x'(n)* will pass through the frequency selective time varying fading channel with additive noise. In this model consider frequency selective time varying fading channel with additive noise, where the channel impulse response can be represented as [8]:

$$h(t)=\frac{1}{\sqrt{L}}\sum_{m=1}^{L}e^{j\left(\theta_m+2\pi f_{Dm}t\right)}\delta\left(t-\tau_m\right) \tag{3}$$

where L is the number of reflected multipaths, τ_m is the delay, θ_m is the phase rotation and f_{Dm} is the Doppler frequency offset of the m^{th} path.

To validate the developed model, Figure 2 shows the simulation results, expressed in terms of symbol error rate (SER) versus SNR , of the system shown in figure 1 under the effect of AWGN and multipath flat fading channel with Rayleigh distribution. From the graph, it is shown that theoretical results [3,8] are compared to the simulation results for both AWGN and multipath channel.

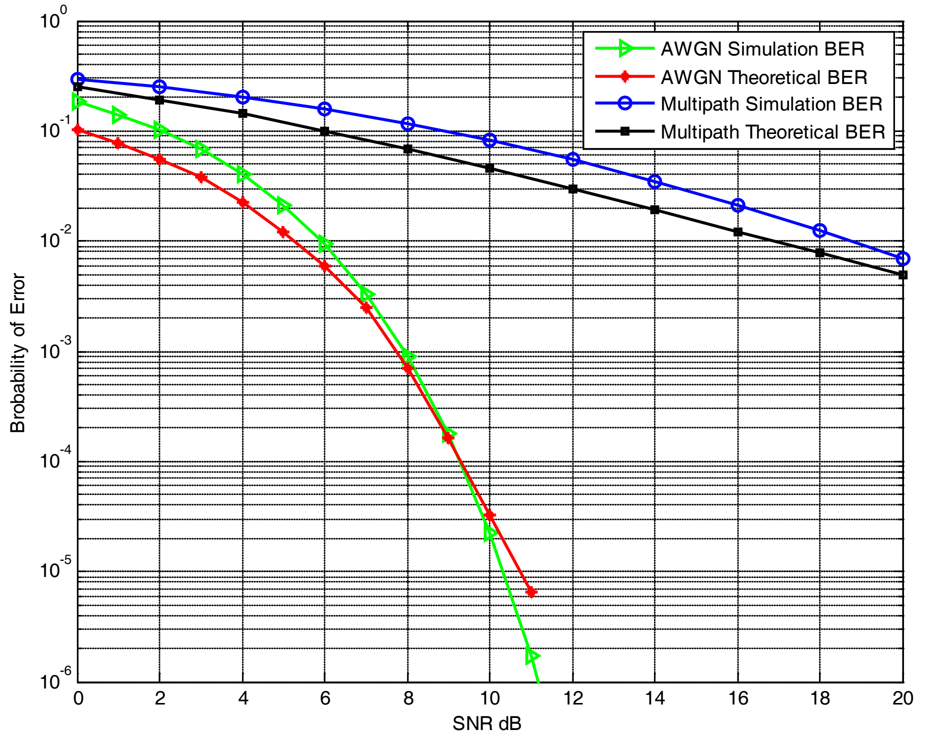


Figure (2) Performance of OFDM system over AWGN and multipath fading channels.

III. Unequal Power Allocation (UPA) Strategy

In this Section, an investigation of the proposed strategy of unequal power allocation will be studied, so a modification to the OFDM scheme is considered, exploiting the inherent structure of the image frames, Unequal Power Allocation (UPA) is assigned to the different parts of the image through successive OFDM symbols. By applying different power allocation to the image data that means applying higher power to the header data and less power to the rest of data, keeping unchanged the average power per frame, and denoted by SNR_{frame}.

In the proposed UPA scheme, the power applied to the data is different and it is not equal, by applying larger power to the header data of the image than the rest of the image data (information data), we guarantee the protection of header data which is important to receive with error free. Due to the relative number of header bits to the rest of data (number of header bits is very small compared to image bits in the frame) of the image the average value of the power is almost equal to the lower value assigned to the information part (rest of data bits without header part). This will allowing the image with very good quality with average power less than the power applied equally to whole frame. The average signal-to-noise ratio is applied to the frame is denoted by SNR_{av} and can be calculated as follows:

$$SNR_{av} = \frac{((SNR_h \times L_h) + (SNR_i + L_i))}{L_d} \quad (4)$$

where

SNR_h is the value of SNR that applied to header data
SNR_i is the value of SNR that applied to the information data.
L_h is the length of the header data.
L_i is the length of the information data.
L_d is the length of image data

From this equation, then

$$SNR_{av} < SNR_{frame} \quad (5)$$

The performance evaluation is done through measuring the quality of the detected image. The simulation is run for the two cases: the conventional OFDM (i.e. fixed time guard and fixed power allocation) in which the fixed values of T_g, denoted by T_{g_all}, are applied to all the frame of the data file of the image. The simulation results are discussed through measuring the detected image quality for both cases. There are two ways to measure the image quality– subjective-based and objective-based. The *root mean square error (RMSE)* and SNR_{image} are the most commonly objective-based measure used due to their simplicity and ease of calculations. *RMSE* is the square root of the mean square error between the original and reconstructed image frame, and is defined as [7].

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{M} \times \mathrm{N}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (g(x,y) - f(x,y))^2} \quad (6)$$

where:

f(x,y) The original image frame
g(x,y) The reconstructed image frame after the decompression process
M×N Dimensions of image frame (matrix)

The SNR image quality is defined as [7]:

$$SNR_{image} = \sqrt{\frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} g(x,y)^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (g(x,y) - f(x,y))^2}} \quad (7)$$

The *SNR* is more commonly used than the *RMSE*, because people tend to associate the quality of an image with a certain range of *SNR*. Although objective fidelity criteria offer a simple and convenient mechanism for evaluating the information loss, most decompressed images ultimately are viewed by human beings. Consequently, in many situations, measuring image quality by the subjective evaluations of a human observer is often more appropriate [7]. In this paper both objective (in terms of SNR) and subjective (in terms of reproduction of received images) are used.

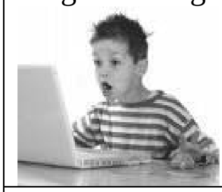
III.1 Simulation Results

Simulation studies have been performed using convolutional coding with OFDM systems considered before. The parameters of the convolution coding are code rate (*r*) equal *1/2* and *1/3* with constraint lengths (*K*) equal *3* and *7* for each of them. For rate *1/2* the function generators are [*6*,*7*] for constraint length *3* and [*133*,*171*] for the constraint length *7*, while for rate *1/3* are [*6*,*7*,*7*] for the constraint length *3*, and [*133*,*145*,*175*] for the constraint length *7*. All these generator vectors are represented in octal form.

Tables 1 to 4 show the simulation results under multipath fading channel coded OFDM. The main operating parameters of the system modeled are: carrier frequency $f_c=1.6GHz$, Doppler frequency $f_D=200Hz$, with sub-channel carriers $N=32$, *16* QAM modulation, and a block of time length $T_b=160\mu s$. The channel is represented by *3*-path fading with one direct path and two reflected paths, with delays (τ_m) equal $15\mu s$ and $30\mu s$. For conventional uncoded OFDM with fixed cyclic time guard and equal power, the effect of time guard and power are illustrated in Table 1. As time guard and power increase the quality of the received image is enhanced. The research goal is to decrease the required power and time guard to get the required image quality. Table 2 shows the best image quality, of the modeled conventional OFDM uncoded and coded for different values of time guard and power, to be compared with the results obtained from the proposed system.

Table 3. shows the performance of the proposed coded OFDM image transmission performance with Unequal power allocation (UPA), which assigns SNR=20 dB for the header part of the image, SNR=15 dB for the information part of the image, and Guard Interval=20% of T_b for both header and information. For conventional OFDM shown in table 2, coded OFDM with rate 1/2 and with constant power of 18 dB and fixed time guard at 20% of T_b satisfy image quality of 95.8720% . Comparing this result with the proposed model with

Table 1. Conventional OFDM image transmission performance with fixed power and time guard.

Original Image 	Received image SNR=5 dB	Received image SNR=10 dB	Received image SNR=15 dB	Received image SNR=20 dB
guard interval =5%				
guard interval =10%				
guard interval =20%				

unequal power allocation shown in Table 3 for the same code rate 1/2, a comparable image quality of 93.8776% is satisfied at the same Guard Interval=20% of T_b but at lower average signal-to-noise ratio at 15.18 dB. The same power saving is observed for code rate 1/3. For uncoded OFDM, the proposed system satisfies 71.161 % of image quality at Guard Interval=20% of T_b but at lower average signal-to-noise ratio at 15.18 dB, compared with the best image quality obtained from conventional model at Guard Interval=25% of T_b and signal-to-noise ratio of 20.0 dB. Better performance can be achieved for the proposed system by adding more time guard for uncoded OFDM but the image quality will be enhanced without increasing the time guard as will be shown in the next section by employing what is called unequal time guard.

IV. Application of Unequal Power Allocation and Unequal Time Guard

Unequal time guard method (UTG) is proposed in [3]. It depends on applying a high value of guard time interval T_g to the header part of the image, that exceeds the maximum excess delay, while the other part of the data file of the image can take a lower value from T_g to increase the amount of information sent and decrease the wasting time due to large value of T_g , under the requirements of detecting the image correctly with a good or at least a reasonable image quality. A brief description of this modification and its application to the proposed model is presented in the previous section. Exploiting the inherent structure of the

Table 2 Conventional OFDM image transmission (coded/uncoded) performance with best image quality.

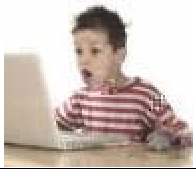
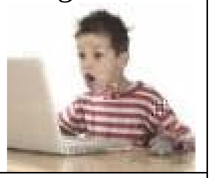
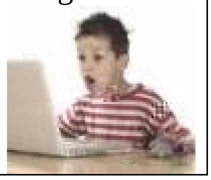
Original image 				
Uncoded OFDM	Power in dB	Guard Interval % Of T_b	Image quality	Received Image 
	20	25	93.1875%	
Coded OFDM r=1/2	Power in dB	Guard Interval % Of T_b	Image quality	Received Image 
	18	20	95.8720%	
Coded OFDM r=1/3	Power in dB	Guard Interval % Of T_b	Image quality	Received Image 
	17	20	98.4648%	

image frames, the modification of the OFDM scheme by changing the time guard between the successive OFDM symbols was done. By adding longer time guard for the header part of the image frame and shorter time guard to the rest of the frame. Investigations and comparison of this new scheme are presented.

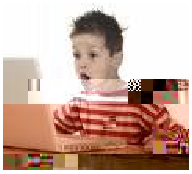
Figure 3 shows a time domain representation of an OFDM signal. The OFDM signal in the time domain consists of a continuous stream of OFDM symbols with a regular period Ts, each containing a guard interval T_g. Figure (3.a) shows a time domain representation of the conventional OFDM signal, where the guard period is fixed during all the frame of the data file of the image. Figure (3.b) shows a time domain representation of the new proposed method (UTG_OFDM) signal, where the guard period applied to the header part of the data file T_{g_h} take a high value, while the guard period applied to the information part T_{g_inf} is reduced to increase the throughput while maintaining the performance. So, the guard interval for unequal time guard OFDM, T_g, can be expressed as follows:

$$T_g = T_{g\_h} + T_{g\_\inf} \qquad (8)$$

where, T_{g_h} is the guard time interval of the header part of the data file of the image and T_{g_inf} is the guard time interval of the information part of the data file of the image. The average guard interval is calculated as follows:

$$T_{gav} = \frac{(T_{g\_h} * L_h) + (T_{g\_\inf} * L_{\inf})}{L_d} \qquad (9)$$

Table 3 OFDM image transmission performance with UPA (Header SNR=20, Information SNR=15, Guard Interval=20 both header and information).

Original image 			
SNR_{Header}= 20dB SNR_{Inf} =15dB GI = 20% of T_b both	Uncoded OFDM unequal power	Coded OFDM code rate 1/2 unequal power	Coded OFDM code rate 1/3 unequal power
Received Image			
Image quality	71.1610%	93.8776%	97.8776%
Average SNR dB	15.1800	15.1800	15.1800

where

- T_{g_h} Time guard of header data
- L_h Length of header data
- T_{g_inf} Time guard of information data
- L_{inf} Length of information data
- L_d Length of data ($L_d = L_h + L_{\inf}$)

In this section, unequal guard time is applied with unequal power allocation for image transmission. This system (UTG_UEP_OFDM) was built as and studied. Simulation results, for the same parameters used in Section III, are shown in Table 4.

In Table 4., for Uncoded OFDM, it is shown that, at SNR_{av}=18.0494 dB and average guard interval Tg_{av}=15.0978 %, the received image with UTG_UPA_OFDM image quality (94.1875%) exceeds the image quality at SNR=20 dB and guard T_g=25 % of conventional OFDM (93.1875%). For Coded OFDM with code rate ½, at SNR_{av}=14.4293 dB and guard interval Tg_{av}=15.1957% the received image with UTG_UPA_OFDM image quality (96.9751%) exceed the image quality at SNR=18 dB and guard Tg=20 % of Conventional OFDM (95.8720%), and compared with UPA_OFDM described and presented in the previous section, the quality of the image is (93.8776%) at SNR_{av}=15.18 dB and fixed guard interval *Tg*=20 %. For Coded OFDM with code rate 1/3, at SNR_{av}=13.18 dB and guard Tg_{av}=15.0978% the received image with UTG_UPA_OFDM image quality (98.3215%) has the same image quality at SNR=17 dB and guard Tg=20 % of conventional OFDM (98.4648%), and compared with UPA_OFDM described and presented in the previous section, the quality of the image is (97.8776%) at SNR_{av}=15.18 dB and fixed guard interval *Tg*=20 %.

(a)

(b)

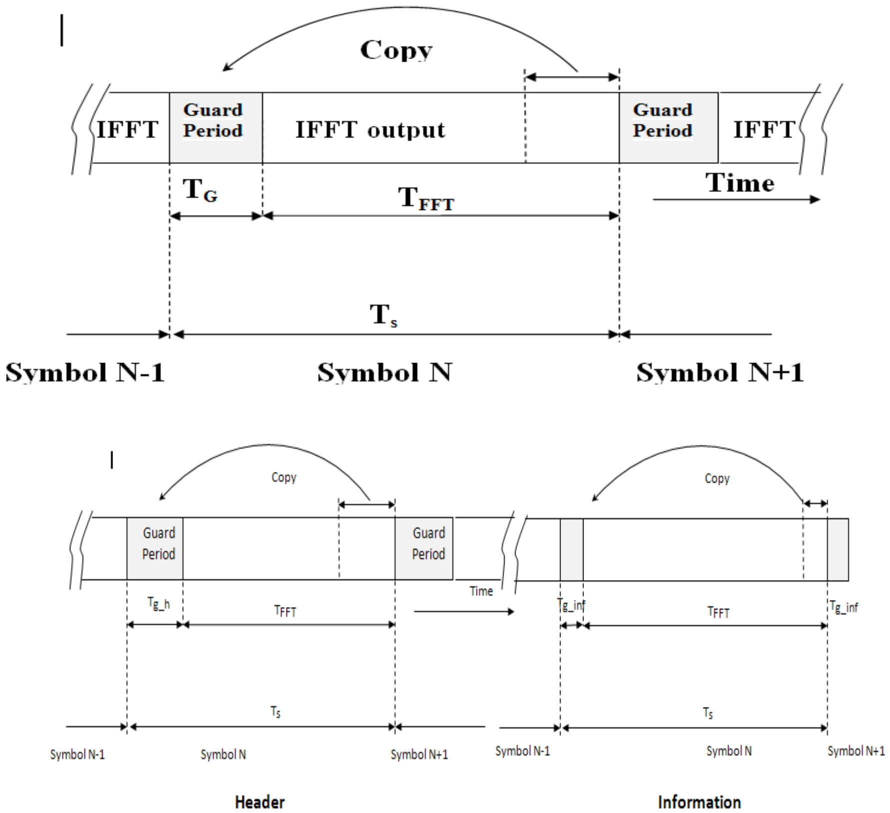


Figure (3) Addition of guard period T_g to an OFDM signal: (a) Conventional OFDM, and (b) UTG_OFDM.

Table 4 OFDM image transmission performance with UTG_UPA_OFDM (unequal time guard and unequal power allocation for the header and information parts).

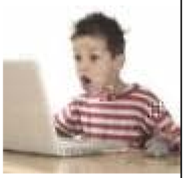
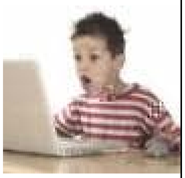
Original image 						
	Average SNR in dB		Average Guard Interval % of T_b		Image quality	Received Image
Uncoded OFDM	Header	information	Header	information	94.1875%	
	20	18	20	15		
	18.0494		15.0978			
Coded OFDM r=1/2	Header	information	Header	information	Image quality	
	20	14	25	15		
	14.4293		15.1957		96.9751%	
Coded OFDM r=1/3	Header	information	Header	information	Image quality	
	18	13	20	15		
	13.1800		15.0978		98.3215%	

Table 5 Comparison of the proposed systems with the conventional OFDM.

		OFDM	UPA_OFDM	UTG_UPA_OFDM
Uncoded OFDM	Image Quality	93.1875%	71.161%	94.1875%
	Average *SNR*	20 dB	15.18 dB	18.0494 dB
	Average Guard Interval % of T_b	25%	20%	15.0978%
Coded OFDM r=1/2	Image Quality	95.872%	93.8776%	96.9751%
	Average *SNR*	18 dB	15.18 dB	14.4293 dB
	Average Guard Interval % of T_b	20%	20%	15.1957%
Coded OFDM r=1/3	Image Quality	98.4648%	97.8776%	98.3215%
	Average *SNR*	17 dB	15.18 dB	13.18%
	Average Guard Interval % of T_b	20%	20%	15.0978%

So, these results show that more saving in Guard time and power were satisfied by employing the two algorithms of unequal power allocation and unequal time guard. Table 5. concludes these results and shows the comparison between the conventional OFDM with the two proposed OFDM systems presented in sections III and IV.

V. Conclusions

Orthogonal Frequency Division Multiplexing (OFDM) promises to be a suitable modulation technique for high capacity wireless communications and will become more important in the future as wireless networks become more relied on.

The model of the OFDM scheme was built and a validation of the model has been done by comparing the simulation results with the analytical bound using *16 QAM* in case of AWGN and Rayleigh Fading Channels.

Coding technique is combined with OFDM to enhance the performance. Exploiting the inherent structure of image transmission, a new proposed method which is based on Unequal power allocation for image transmission (UPA_OFDM) is introduced for improving the performance, while keeping the average power per frame unchanged. To get further improvement, UPA_OFDM was also applied with unequal time guard (UTG), UTG_UPA_OFDM. Simulation results through images at different time guard values T_g and *SNR* indicate that the performance was improved at a lower average T_g and lower average SNR.

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