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OPTIMIZATION OF OFDM PARAMETERS USING TAGUCHI APPROACH FOR IMPROVING PERFORMANCE OF COMMUNICATION SYSTEM

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Abstract

OFDM's ability to efficiently utilize spectrum, achieve high data rates, and maintain robustness in challenging channel conditions has made it a fundamental technology in modern communication systems. In view of this, it is essential to obtain an optimized set of OFDM parameters providing minimum bit error rate. In this work, in the initial phase, experimentation is done to study the effect of variations in individual parameter of OFDM on bit error rate (BER) of OFDM scheme. In the second phase of work, in order to find optimized combination of OFDM parameters, Taguchi optimization technique is applied with the objective to minimize BER. Investigating how the cyclic prefix affects the performance of an OFDM (Orthogonal Frequency Division Multiplexing) system is crucial for optimizing BER (Bit Error Rate) performance and spectral efficiency across different modulation schemes such as BPSK, QPSK, 16-QAM, and 64-QAM. The cyclic prefix (CP) in OFDM systems plays a significant role in mitigating inter-symbol interference (ISI) caused by multipath propagation and in simplifying the equalization process. BER curves are obtained and compared for various lengths of the cyclic prefix. In similar manner, the experimentation is done for investigating the effect of variations of other parameters of OFDM namely FFT length and signal to noise ratio individually on bit error rate of OFDM scheme. Here, the statistical analysis technique referred to as ANOM (Analysis of Means) is utilized to examine experimental data and assess the importance of different factors and their interactions on the system's performance. In this work, optimized set of values of cyclic prefix, bit error rate, FFT length and signal to noise ratio is obtained using Taguchi approach to minimize the BER of OFDM scheme.

Keywords:

Orthogonal Frequency Division Multiplexing (OFDM), Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), Taguchi optimization, Cyclic Prefix (CP)

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has gained significant importance in modern communication systems due to its numerous advantages and applications. It is particularly prevalent in applications like wireless communication, digital broadcasting, and DSL internet access. At its core, OFDM is a method of transmitting large amounts of digital data over a radio wave by splitting the data into several parallel data streams, each transmitted over its own subcarrier frequency. One of the key features of OFDM is its ability to combat the effects of multipath interference and frequency-selective fading, which are common challenges in wireless communication. This is achieved by dividing frequency spectrum into parallel orthogonal sub carriers, which are closely spaced but mutually orthogonal. This means that even if some subcarriers experience interference or fading, others can still carry data effectively [1].

The process of transmitting data using OFDM involves several steps. First, the digital data stream is divided into parallel streams, each modulated onto a separate subcarrier. These subcarriers are then combined into a single composite signal for transmission. At the receiver, the composite signal is separated back into its constituent subcarriers, and the data streams are demodulated and combined to reconstruct the original data. OFDM offers several advantages over other modulation techniques. It is highly efficient in terms of spectral usage, allowing for high data rates over limited bandwidth. It is also robust against multipath interference and frequency-selective fading, making it well-suited for high-speed data transmission in challenging wireless environments. Overall, OFDM plays a crucial role in enabling the high-speed, reliable communication systems that we rely on in our interconnected world today [2]. In consideration of the above discussion, the significant contributions of this work are as follows:

1. In this work, in the initial phase, experimentation is done to observe the effect of variations in individual parameters of OFDM on bit error rate (BER) of OFDM scheme.
2. In the second phase of work, in order to find optimized combination of OFDM parameters, Taguchi optimization technique is applied with the objective to minimize BER.
3. Statistical analysis techniques such as ANOM (Analysis of Means) are used to analyze experimental data and determine the significance of various factors and their interactions on the system's performance. This helps identify the most influential factors and optimize their settings accordingly.

Rest of the paper is organized as follows: Section 2 discusses simulation results of experimentation carried to out to observe the effect of individual parameters of OFDM on the BER. Section 3 presents a discussion about Taguchi methods and its implementation in the context of optimizing OFDM parameters. Section 4 presents conclusions.

2. EFFECT OF VARIATIONS IN OFDM PARAMETERS ON BER

This section presents results of simulation experiments carried out to observe effect of variations in individual OFDM parameters on BER. OFDM parameters considered for variation are as follows:

- Modulation Techniques
- FFT Size
- Cyclic prefix
- Signal to Noise Ratio (SNR)

Simulation model for OFDM system developed in MATLAB using a sample modulation scheme Binary Phase Shift Keying (BPSK) is presented in the Fig.1. Bernoulli binary block is used for random input to the system. This model calculates BER for various OFDM experimentations.

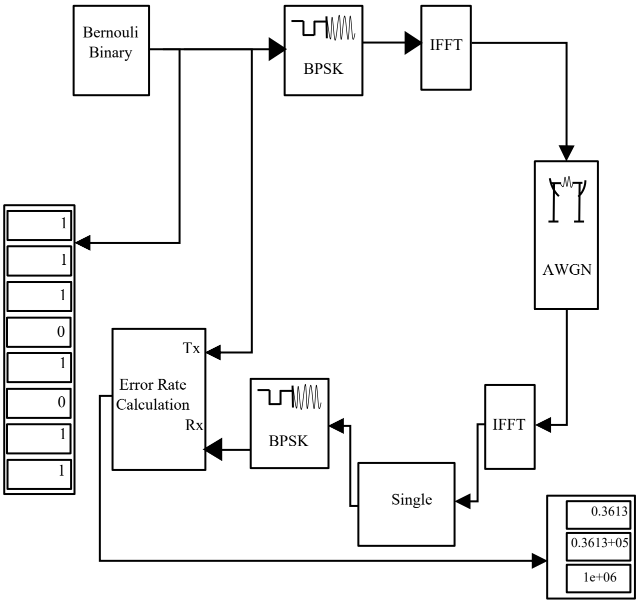

Fig.1. Simulation model using BPSK

Experimentation has been conducted to investigate the variations of various factors under consideration on the BER of the OFDM scheme, based on the simulation model for OFDM shown in the Fig.1. The following discussion states the outcomes of each of these unique parameter variations. For experimenting, the Additive White Gaussian Noise channel (AWGN) is utilized. Plots of BER vs SNR are produced by combining certain combinations of these different OFDM parameters.

- The results of effect of variations in modulation scheme for FFT length of 1024, are demonstrated in the Fig.2. It is observed that the SNR required to achieve the same BER increases as number of constellation points in the applied digital modulation scheme goes on increasing.

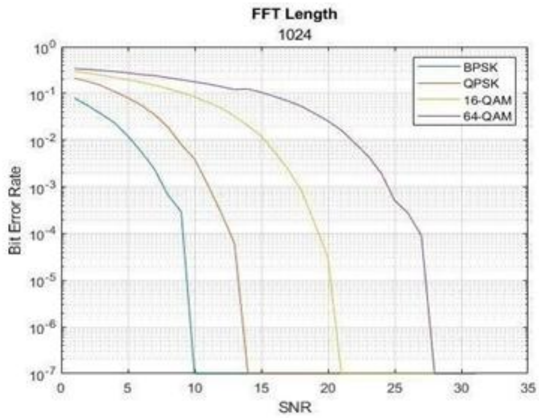

Fig.2. BER vs. SNR for variations in modulation scheme, for fixed FFT length 1024

- The results of effect of variations in CP length for different modulation schemes (BPSK and 64-QAM) and different FFT lengths (64, 256 and 1024) are demonstrated in the Fig.3 to Fig.6. It is observed that the SNR required to achieve the same BER increases as CP length goes on increasing.

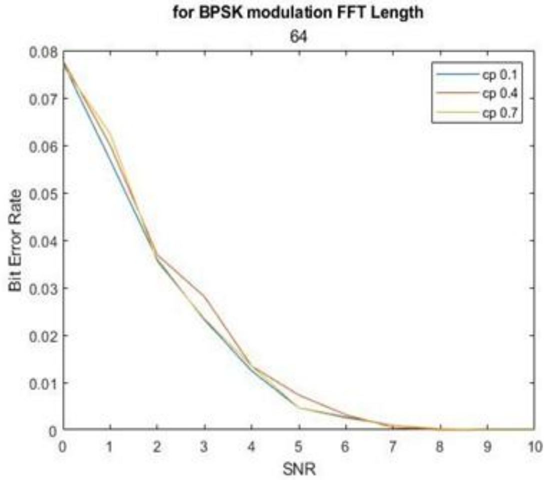

Fig.3. BER vs. SNR for variations in CP lengths (BPSK, FFT Length 64)

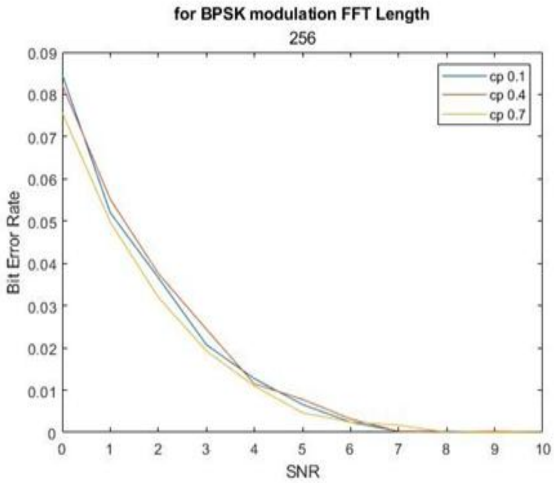

Fig.4. BER vs. SNR for variations in CP lengths (BPSK, FFT Length 256)

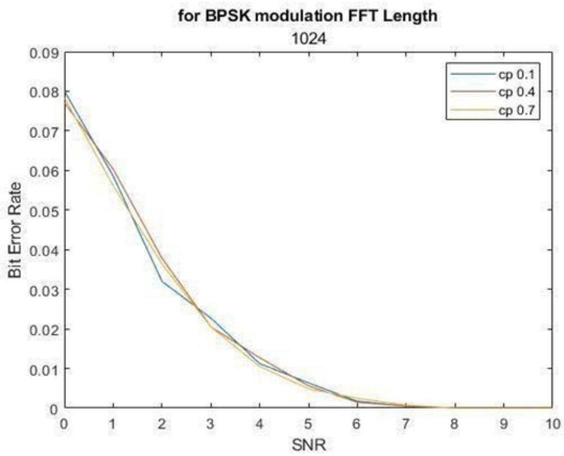

Fig.5. BER vs. SNR for variations in CP lengths (BPSK, FFT Length 1024)

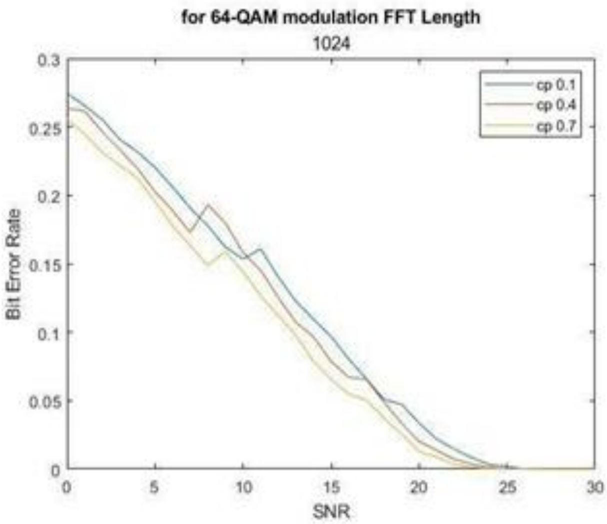

Fig.6. BER vs. SNR for variations in CP lengths (64-QAM, FFT Length 1024)

The preceding experimentation reveals that the performance of OFDM system is highly dependent on selection of parameters like modulation scheme, FFT length and CP length. For superior performance of the OFDM system, it is necessary to derive an optimized combination of parameters using a suitable optimization technique. The Taguchi method is applied for optimization in this work.

3. TAGUCHI OPTIMIZATION APPROACH

In full factorial method for design of experiments, if process depends on m number of parameters, each having n number of levels; to obtain the best possible combination, total number of experiments required to be conducted is n^m. This approach is particularly helpful when the number of parameters is less than or equal to 4, and each parameter does have 2 levels [3].

It becomes essential to perform many trials for getting an optimized set of parameters if the number of parameters and their levels increase. In such a scenario, the process becomes impractical if one uses a conventional full factorial method for designing experiments.

In the literature survey, it is observed that following optimization techniques are already applied for OFDM optimization by the researchers.

- **Analytical Methods:** Mathematical models and optimization algorithms are utilized to derive optimal OFDM parameter configurations based on specific performance criteria [4]-[5].
- **Heuristic Algorithms:** Metaheuristic optimization techniques like genetic algorithms, particle swarm optimization, and simulated annealing are applied to search for near-optimal OFDM parameter settings [6]-[7].
- **Machine Learning Approaches:** Data-driven optimization methods, including neural networks and reinforcement learning, are increasingly being employed to learn optimal OFDM parameter configurations from empirical data [8]-[9].

As mentioned earlier, Taguchi optimization approach is applied in this work to get optimum combination of OFDM parameters. This method achieves optimum solution with a significantly a smaller number of trials using an orthogonal array. Additionally, the Taguchi method is more suitable over other techniques as it facilitates simultaneous optimization of multiple parameters in a system.

It emphasizes the importance of understanding and controlling variation to achieve robust and reliable results [10]. Taguchi method employs a concept of signal-to-noise ratio, referred as Taguchi SNR (TSNR) in this work, for analyzing the experimental results and getting the optimized set of OFDM parameters. The optimized set of parameters obtained using the Taguchi method is robust and not affected by other environmental conditions and noise [11]. In view of this, the Taguchi method, a novel approach for OFDM parameter optimization, is applied in this work.

3.1 KEY PARAMETERS OF OFDM

Performance of communication systems employing OFDM is highly dependent on various parameters like FFT size, cyclic prefix length, modulation scheme and SNR.

Optimizing OFDM parameters involves fine tuning of these parameters to achieve the best performance for a specific communication system. These parameters are briefly described in this subsection.

- **FFT Size:** The number of subcarriers used in OFDM is determined by the size of the Fast Fourier Transform (FFT). Larger FFT sizes can offer better frequency resolution but may increase complexity and latency. Optimizing the FFT size involves considering trade-offs between frequency resolution, complexity, and latency [12].
- **Cyclic Prefix (CP) Length**: The cyclic prefix is a copy of the end of the OFDM symbol that is preceded to the beginning to mitigate ISI. Optimizing the CP length involves choosing a length that provides adequate protection against ISI without introducing excessive overhead [12].
- **Modulation Scheme:** OFDM systems often use various modulation schemes (e.g., QPSK, 16-QAM, 64-QAM) to transmit data. The choice of modulation scheme can affect the data rate and robustness against noise and interference. Optimizing the modulation scheme involves selecting the scheme that provides the highest data rate while maintaining an acceptable error rate [12].
- **Signal-to-Noise Ratio (SNR):** While assessing the communication quality of OFDM, it is crucial to consider the SNR. The capacity of the system to distinguish the signal from background noise is determined by the SNR. Improved signal quality is correlated with higher SNR, and vice versa, which influences the dependability of data transfer. Robustness of OFDM to frequency-selective fading is dependent on SNR, which is crucial in various communication environments. Achieving optimum value of SNR ensures efficient data transmission and reception, which is vital for reliable wireless communication systems [12].

3.2 IMPLEMENTATION OF TAGUCHI METHOD IN THE CONTEXT OF OPTIMIZATION OF OFDM

3.2.1 Design of Orthogonal Array:

Orthogonal Arrays are structured experimental designs that allow researchers to efficiently explore the effects of multiple factors (parameters) and their interactions on a performance of the system. Orthogonal arrays ensure that all combinations of factor-levels are tested while minimizing the number of experiments required. As discussed in the subsection 3.1, modulation techniques, FFT size, cyclic prefix, and signal to noise ratio are the four key parameters responsible for the OFDM performance. In this work, these four parameters are considered with four levels of variation, as shown in the Table.1.

Table.1. Parameters and their levels used in the optimization

Parameter	Description	Level 1	Level 2	Level 3	Level 4
A	Modulation Technique	BPSK	QPSK	16 QAM	64 QAM
B	FFT size	16	64	256	1024
C	Cyclic Prefix	0.1	0.2	0.5	0.7
D	SNR	1	2	3	4

PTo find the best combination of process parameters and produce the minimum BER, a full-factorial design would need to test 256 possible combinations. It is evident that carrying out so many trials is a challenging endeavor. If one applies Taguchi method utilizing an L_{16} orthogonal array, only 16 trials are enough to optimize the BER of OFDM. The Table.2 illustrates the construction of an L_{16} orthogonal array with four process parameters, each with four levels of variation [13]. The L_{16} orthogonal array displays the appropriate combination of OFDM parameters. For example, the combination (1, 4, 4, and 4) displayed in test 4 of the Table.2 indicates that BPSK modulation type was used, FFT size is 1024, and SNR and cyclic prefix values are set to 4 and 0.7 respectively.

3.2.2 Taguchi Signal to Noise Ratio:

Taguchi introduced a concept of signal-to-noise ratio as a quality characteristic to be optimized (referred as TSNR). In the context of the Taguchi method, "signal" refers to the desired output or performance metric, while "noise" represents variation or factors that degrade performance. The goal is to maximize the signal-to-noise ratio to achieve robustness and quality. There are three types of SNR, namely, HB (higher the better), NB (nominal the better) and LB (lower the better). The type of TSNR utilized in this work is LB. The following equation is used to calculate the kind of SNR (lower ordering) employed in this work.

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum J^2\right)$$

where J is the bit error rate (the objective function value) for particular trial and n is the number of replications under the same experimental conditions [14]. The bit error rate is calculated using Simulation model shown in the Fig.1. Calculations of TSNR values are calculated for different trials of L_{16} orthogonal array and are presented in the Table.3.

Table.2. L_{16} Orthogonal Array of Taguchi method

Expt. No.	Parameter (L16)				Modulation Technique	FFT size	Cyclic Prefix	SNR
	A	B	C	D				
1	1	1	1	1	BPSK	16	0.1	1
2	1	2	2	2	BPSK	64	0.2	2
3	1	3	3	3	BPSK	256	0.5	3
4	1	4	4	4	BPSK	1024	0.7	4
5	2	1	2	3	QPSK	16	0.2	3
6	2	2	1	4	QPSK	64	0.1	4
7	2	3	4	1	QPSK	256	0.7	1
8	2	4	3	2	QPSK	1024	0.5	2
9	3	1	3	4	16 QAM	16	0.5	4
10	3	2	4	3	16 QAM	64	0.7	3
11	3	3	1	2	16 QAM	256	0.1	2
12	3	4	2	1	16 QAM	1024	0.2	1
13	4	1	4	2	64 QAM	16	0.7	2
14	4	2	3	1	64 QAM	64	0.5	1
15	4	3	2	4	64 QAM	256	0.2	4
16	4	4	1	3	64 QAM	1024	0.1	3

Table.3. Calculation of Taguchi SNR

Expt. No.	Modulation Technique	FFT Length	Cyclic Prefix	SNR	BER	Taguchi SNR
1	BPSK	16	0.1	1	0.055	25.240
2	BPSK	64	0.2	2	0.038	28.473
3	BPSK	256	0.5	3	0.023	32.653
4	**BPSK**	**1024**	**0.7**	**4**	**0.013**	**37.993**
5	QPSK	16	0.2	3	0.113	18.962
6	QPSK	64	0.1	4	0.081	21.788
7	QPSK	256	0.7	1	0.180	14.895
8	QPSK	1024	0.5	2	0.146	16.737
9	16 QAM	16	0.5	4	0.207	13.664
10	16 QAM	64	0.7	3	0.227	12.864
11	16 QAM	256	0.1	2	0.239	12.443
12	16 QAM	1024	0.2	1	0.272	11.318
13	64 QAM	16	0.7	2	0.296	10.583
14	64 QAM	64	0.5	1	0.320	9.902
15	64 QAM	256	0.2	4	0.277	11.138
16	64 QAM	1024	0.1	3	0.317	9.979

From Table.3, it is evident that trial 4 results in the optimized set of parameters for OFDM system, which results in the highest TSNR and consequently, the lowest bit error rate. The parameter set for this trial is:

- Modulation scheme: BPSK
- FFT length: 1024
- Cyclic prefix: 0.7
- Signal to Noise Ratio (SNR): 4

It is observed that optimal combination generated by executing experiments as per L_{16} orthogonal array (Table.3) and after analysis of means (Table.4) is same.

3.2.3 Analysis of Means (ANOM):

Taguchi method employs a statistical analysis technique namely Analysis of Mean (ANOM) to analyze experimental data generated from conducting experiments as prescribed in Taguchi Orthogonal array. It helps to determine optimum level of each factor and essentially gives the best combination of parameters that optimizes the objective function. In this step, an average of the SNR of each parameter is calculated at each level for each process parameter [15]. The maximum of the mean of the SNR for each of the parameters is used to decide the optimal combination of the parameters.

In this work, ANOM is applied to TSNR values resulted in the Table.3 to optimize OFDM parameters to achieve minimum BER. The Table.4 presents the results of ANOM technique.

Table.4 Response Table of Average of SNRs (ANOM)

Level ↓	Parameters			
	A	B	C	D
1	**31.08**	17.11	17.36	15.34
2	18.09	18.25	17.47	15.06
3	12.57	17.78	18.24	18.61
4	10.04	**19.00**	**19.08**	**21.14**

Optimized combination of OFDM parameters obtained using analysis of means (as shown in the Table.4) of Taguchi SNRs (obtained as per Table.3), is shown below:

- Modulation scheme: BPSK
- FFT length: 1024
- Cyclic prefix: 0.7
- Signal to Noise Ratio (SNR): 4

4. CONCLUSION

In this work, initial experimentation is carried out to investigate and observe the effect of variations in individual parameters of OFDM on bit error rate (BER) of OFDM scheme. This work also emphasized necessity to derive optimum combination of OFDM parameters in limited number of trials so as to obtain minimum BER in OFDM system. Taguchi optimization approach is applied in this work involving only 16 experiments instead of 256 experiments that would have been required in the full factorial design approach.

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