Enhancing OFDM Performance: An Analysis of Active Interference Cancellation with Subcarrier Weighting and Sidelobe Suppression

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ABSTRACT

The wireless communications with high data rates entails a substantial need for additional spectral resources through more flexible and efficient use of the available spectrum. Orthogonal frequency division multiplexing (OFDM) has been a prime candidate for spectrum pooling-based wireless transmission systems since subcarriers in the vicinity of the licensed users can be deactivated in order to minimize interference from the unlicensed user. Orthogonal frequency division multiplexing (OFDM) is a recognized transmission technique for Cognitive radio (CR) systems but one of the major drawbacks of OFDM scheme is its out-of-band (OOB) leakage due to high spectral sidelobes. The major challenge that OFDM has to deal with is high spectral sidelobes. Active interference cancellation (AIC) and subcarrier weighting (SW) are recognized techniques for sidelobe suppression. This paper proposes a joint SW-AIC scheme which has the ability to produce much deeper notch as compared to individual AIC and SW and system parameters can be adjusted depending on user's requirements. By using both the technique we will suppress the sidelobes.

In AIC Technique, instead of turning off a large number of tones, we define two special tones at the edge of the interference band and these two tones can sufficiently cancel the interference in the band. The tone values can be arbitrarily determined without affecting the information tones due to the orthogonality relationship. We call these special tones Active Interference Cancellation (AIC) tones. We will discuss how to compute the AIC tones, and how to create the notch using the minimum number of tones, or, equivalently, how to maxime the spectrum efficiency. The Subcarrier Weighting (SW) Technique is based on the multiplication of the used subcarriers with subcarrier weights. The subcarrier weights are determined in such a way that the sidelobes of the transmission signal are minimized according to an optimization algorithm which allows several optimization constraints. As a result, sidelobe suppression by subcarrier weighting reduces OFDM sidelobes by more than 10 dB in the average without requiring the transmission of any side information.

Active Interference Cancellation (AIC) scheme is suitable for the transmissions which can reduce throughput but will increase BER degradation, for e.g. important data losses and performance of software. On the other hand SW scheme is best suited for the systems which can reduce BER degradation but also reduce throughput of the system such as live video/audio streaming. But for a dynamic system where requirements such as BER and throughput of a cognitive user are changing with time, we need to have a scheme which can dynamically change its parameters to best serve the user needs. Motivated by this, we propose a SW-AIC scheme which provides us with various knobs for adjusting system parameters. Apart from this, interference reduction capability of SW-AIC scheme is far better than individual AIC or SW.

KEYWORDS: Cognitive Radio, Orthogonal Frequency Division Multiplexing, Active Interference ancellation, Subcarrier Weighting, BER, Sidelobe Suppression

I. INTRODUCTION

One of the most fundamental needs of human beings is communication. The presently popular wireless communication concept was introduced by Nicola Tesla [1], whose experiment has shown the possibility of radio frequency energy transmission and usefulness for telecommunication of information. After the rapid developments in the field of Information Technology over a decade, wireless communication has emerged as the most preferred way of exchanging information all over the world. We are surrounded by so many wireless devices such as Mobile Phones, Wi-Fi (IEEE 802.11), Bluetooth devices, WiMAX (IEEE 802.16), etc. In today's world, there is a high demand of very high speed wireless services but there is a scarcity of spectrum hence the chances of interference between two systems is increasing. The exponential growth of wireless

communication applications has increased the necessity of radio frequency spectrum resources. The frequency spectrum is a very precious resource in wireless communication but not unlimited. In the current spectrum framework, most of the available frequency bands have been already allocated to the existing applications [2], which has caused in the shortage of spectrum for new applications. However, the spectrum studies show an inefficient usage of most of the licensed spectrum in a specific location or period of time [3].
Figure 1.1 demonstrates an estimation of spectral occupancy (9 kHz- 1 GHz) measurement campaign led at the Information Technology and Telecommunications Center (ITTC) on 31st August, 2005 [4]. We can analyze from the figure, the presence of multiple white spaces in the spectrum in the licensed portions demonstrating that most parts of the allocated spectrum are unused. Consequently, the requirement for a novel spectrum allocation technique has been recognized. Cognitive Radio (CR) [5] technology came in the picture which showed a new way to efficiently utilize the spectrum in more opportunistic manner. CR detects the Primary Users (PU) and also tries to protect it by using interference mitigation technique.

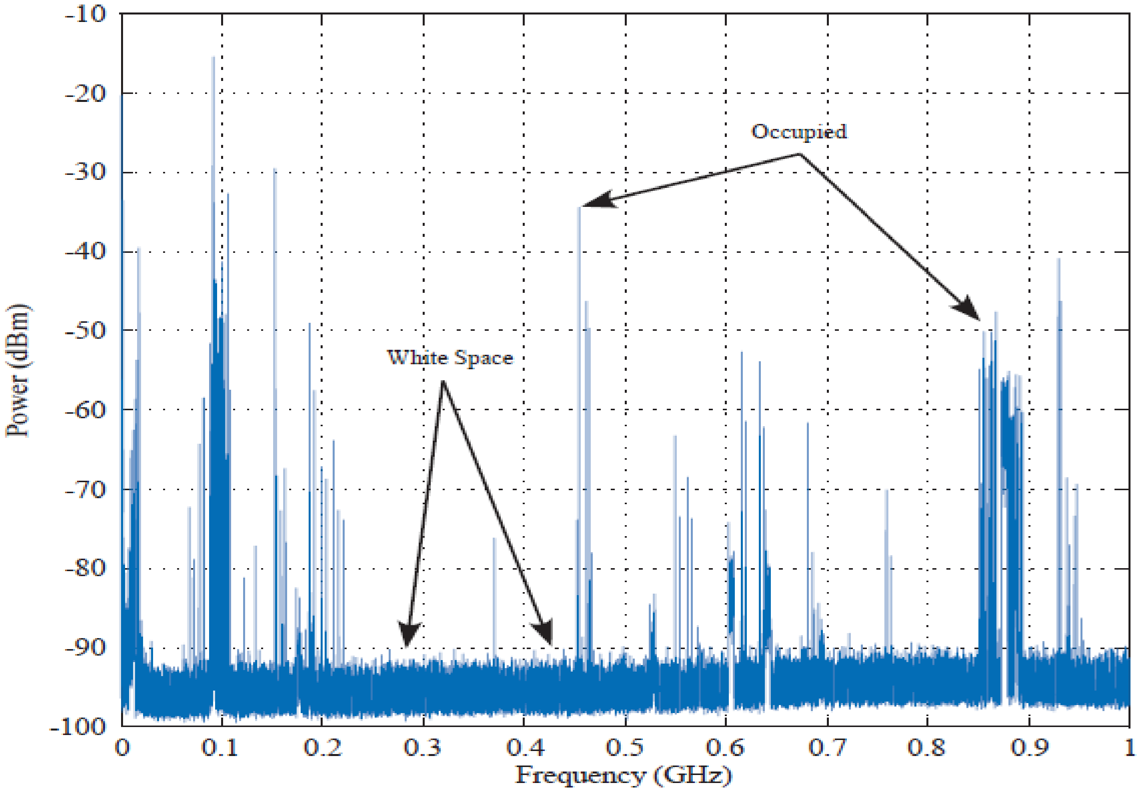

Figure 1. Spectral occupancy measurements (9 kHz – 1 GHz)

OFDM (Orthogonal Frequency Division Multiplexing) comes out as a leading candidate, which shows its suitability for Ultra Wide Band frequencies. The problem faced while using OFDM systems is the interference occurred in the vicinity of bands by the secondary systems to the legacy or primary systems. The interference has a negative effect on the quality and performance of the OFDM systems [6] [7]. Thus, the objective of this thesis is to focus on the development of an algorithm which will reduce the interference caused by the secondary users in the frequency band by not affecting their system performance.

In orthogonal frequency division multiplexing communication systems, sidelobe suppression is currently the main focus of research to minimize the interference. OFDM systems are the focus of many researchers and some sidelobe suppression techniques are also proposed by them which are accessible in the literature. These techniques reduce the interference using sidelobe suppression technique, but they have drawbacks like transmission of side or unwanted information to the receiver end and increase number of complex calculations at the transmitter. Because of these reasons, it is vital to develop efficient algorithms which will find the solution to keep up the framework with less complexity.

II. MATERIALS AND METHODS

Polynomial Cancellation Coding

This technique has been proposed [9] to provide several benefits to the OFDM based communication systems. Specifically, this technique named Polynomial Cancellation Coding (PCC) reduces the Intercarrier Interference

(ICI) between transmitter and receiver by frequency shifting [10]. In this method, a weighted group of subcarriers is transmitted to increase the delay rate. By this the notch depth will increase in a good manner. For '*m'* subcarriers, the relative weighting in PCC is given by coefficients of the polynomial $(1-x)^{m-1}$.
Mathematically, the fourier transform of individual subcarrier is given by:

$$X_k(f) = \sqrt{N}T_s(-1)^k \left[\frac{\sin(\pi(fT_sN-k))}{\pi(fT_sN-k)}\right] \tag{1}$$

Therefore, the spectrum is shown as follows:

$$X_k(f) = \sqrt{N}T_s \left[\frac{\sin(\pi(fT_sN-k))}{\pi(fT_sN-k)}\right]^2 \tag{2}$$

Observing equation (1.1), we can analyse that the spectrum of individual subcarrier falls of at rate of $1/(f^2N^2)$. For N subcarriers, the rate of spectrum decay can be given by $1/(f^2N)$. Let us consider when m=2, adjacent subcarriers having relative weighting of +1 and −1 having values $X_0 = -X_1$, $X_2 = -X_3$ and so on. Therefore, the Fourier transform of weighted subcarrier can be calculated as:

$$X_k(f) - X_{k+1}(f) = \sqrt{N}T_s\cos(\pi k)\left[\frac{\sin(\pi(fT_sN-k))}{\pi(fT_sN-k)}\right] - \sqrt{N}T\cos(\pi(k+1))\left[\frac{\sin(\pi(fT_sN-k-1))}{\pi(fT_sN-k-1)}\right] \tag{3}$$

For even values of *k*, the above equation can be given as:

$$X_k(f) - X_{k+1}(f) = \left[\frac{-\sqrt{N}T_s\sin(\pi(fT_sN-k))}{\pi(fT_sN-k)(fT_sN-k-1)}\right] \tag{4}$$

and the spectrum of weighted pair is given by

$$S_{k,k+1}(f) = T_s\left[\frac{N_s\sin(\pi(fT_sN-k))}{\pi(fT_sN-k)(fT_sN-k-1)}\right]^2 \tag{5}$$

As evaluated in equation (4), the drooping of Power spectrum of weighted subcarriers is given at the rate of $1/(f^4N^4)$ which is faster than individual subcarrier. Taking large value of *m* results in faster roll off which can be given as $1/(f^{2m}N^{2m-1})$. The effect of roll off using PCC for *m* = 2 can be seen in Fig 2.

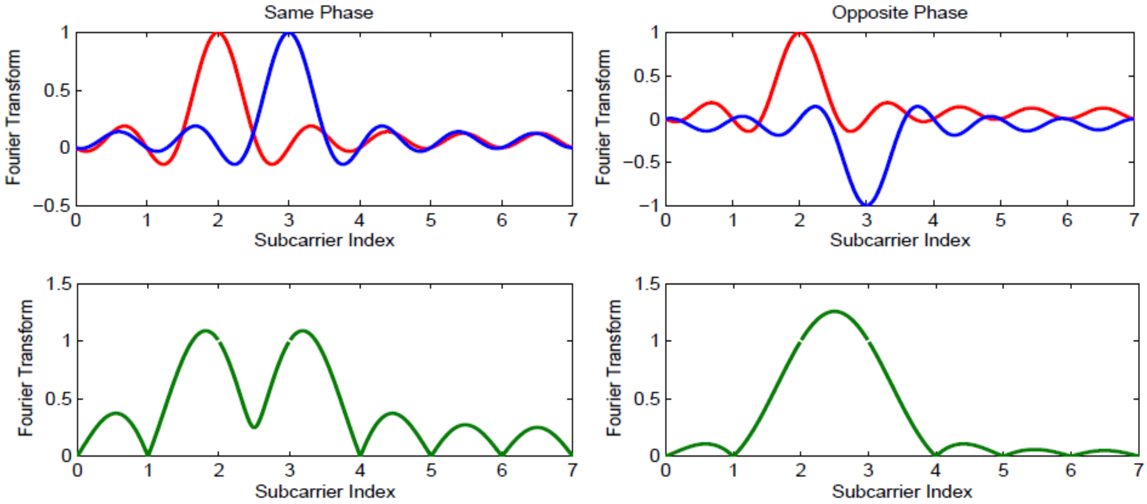

Figure 2. Showing the effect of PCC on adjacent two subcarriers

Raised Cosine Windowing

Leveling of the time-domain waveform of an OFDM system by using a raised cosine filter is the windowing technique [11] which improves the attenuation by subcarrier nulling. In this method, the raised cosine windowing function needs not to be in sync with the receiving end. An attenuation of nearby -25 dB can be achieved with this technique for an OFDM system. This value can also be achieved when the raised cosine roll-off factor (β) is equal to 1, which is not adequate.
The filter vector g = {g_n} can be given as:

$$g_n = \begin{cases} \frac{1}{2} + \frac{1}{2}\cos(\pi + \frac{\pi n}{\beta N_T}), \ for 0 \le n \le \beta N_T \\ 1, \ for \beta N_T \le n \le N_T \\ \frac{1}{2} + \frac{1}{2}\cos(\pi \frac{n - N_T}{\beta N_T}), \ for N_T \le n \ge (1+\beta) N_T \end{cases}$$

where $N_T = N + N_g$ is the symbol length (in samples) and β is the roll off factor. The total symbol length is $(1+\beta)\,N_T$.

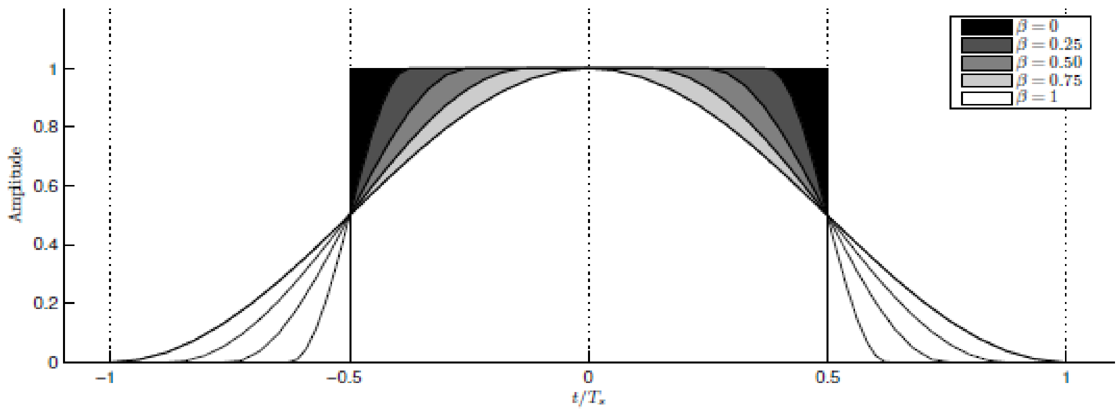

Figure 3. RC windowing with different rolloff (β) values

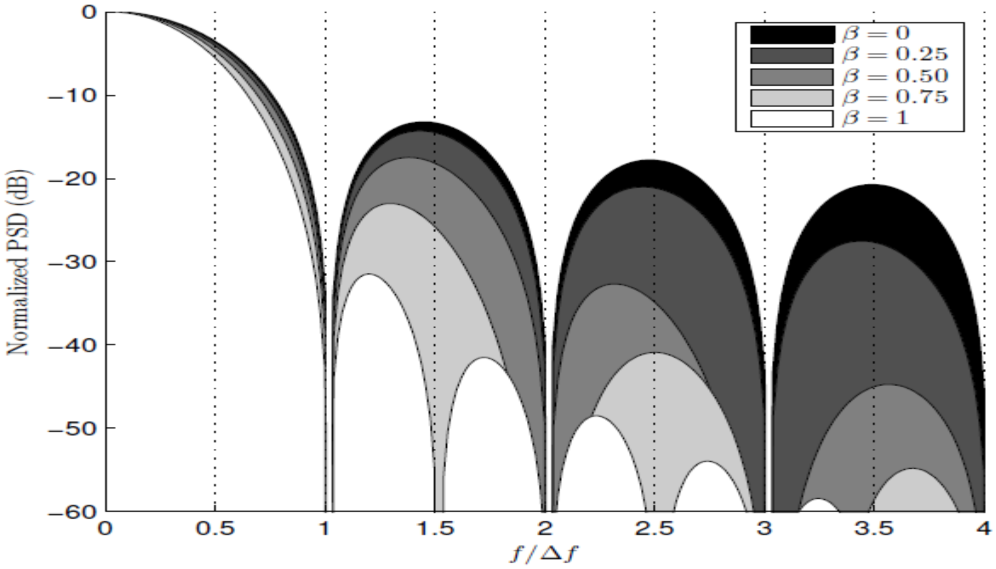

Figure 4. Rolloff effect of an OFDM subcarrier

OFDM IMPAIRMENTS

An OFDM signal gets distorted by different drawbacks in different phases of the communication system. The explanation behind the issue may be the time-spreading, or time difference in the wireless multipath channel, timing and carrier frequency difference between the transmitter and recipient as an equipment based issue, or issues that arises with the attributes of the OFDM waveform, for example, high peak- to- average power ratio (PAPR) also, out-of-band emission. OFDM have sinc and cosine pulse spectrum which results in high spectral sidelobes. The out-of-band emission creates interference to other users of the spectrum, known as Adjacent Channel Interference (ACI). Particularly with the rise of Cognitive Radio (CR) applications whose most grounded competitors is OFDM technology, spectral regulation is a basic concern. There are different countermeasures to spectral sidelobes that can be considered less than two main principles classifications as information independent strategies, which are generally less difficult to execute, and data dependent techniques, which considers the information images for spectral sidelobe suppression. The occurrence of sidelobes in the signal transmission can likely produce the interference within the neighboring legacy systems or other rental users. A traditional way of reducing the effect of sidelobes is to deactivate the required number of adjacent tones which are known as guard subcarriers although it results in the significant loss of throughput. To overcome this loss an effective sidelobe suppression scheme is used which can improve the spectral efficiency of a spectrum. Different types of sidelobe suppression techniques have been proposed by the researchers. Some of them includes Adaptive symbol transition, Windowing technique, Active Interference Cancellation (AIC) [16], Cancellation Carriers (CC), Subcarrier Weighting (SW) [25, 46], Projection Precoder.

III. RESULTS AND CONCLUSION

The effect of w_{min} and w_{max} on notch depth is important in plotting BER graph as shown in Figure. Observing the BER curves, it is clear that the BER performance improves in joint SW-AIC scheme as compared to conventional schemes of SW and AIC methods explained in previous chapters. But the improvement in notch depth is achieved by paying prize in terms of degraded power spectrum performance due to numerical complexity which is shown in. The notch depth increases with increasing the difference between w_{min} and w_{max} which is in accordance with theoretical analysis. In simulating the BER performance, we are assuming that the position of interference band is known at the receiver, hence the receiver directly rejects the interference tones which may or may not be the case in real implementation of OFDM system. Now in order to compare joint SW-AIC techniques with each other and with conventional- SW technique, there is need to set some common parameter fixed. Here we are assuming the length of weight locus in the direction aligned with original symbol to be fixed.

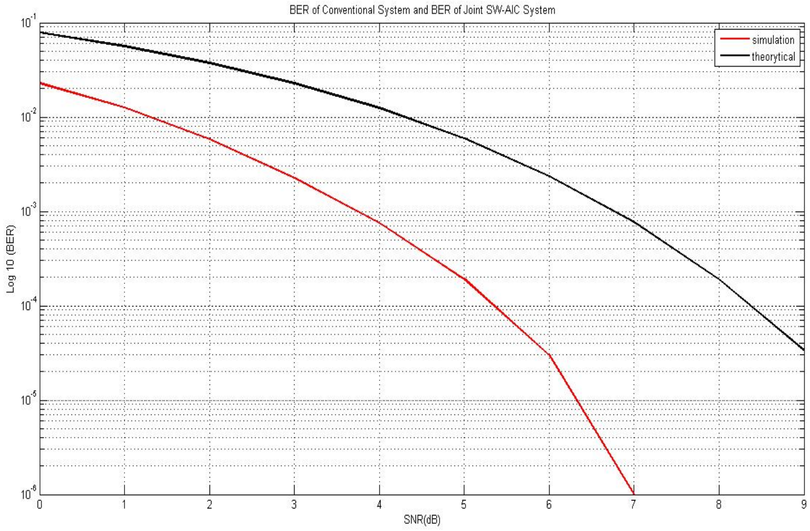

Figure 5.0 BER

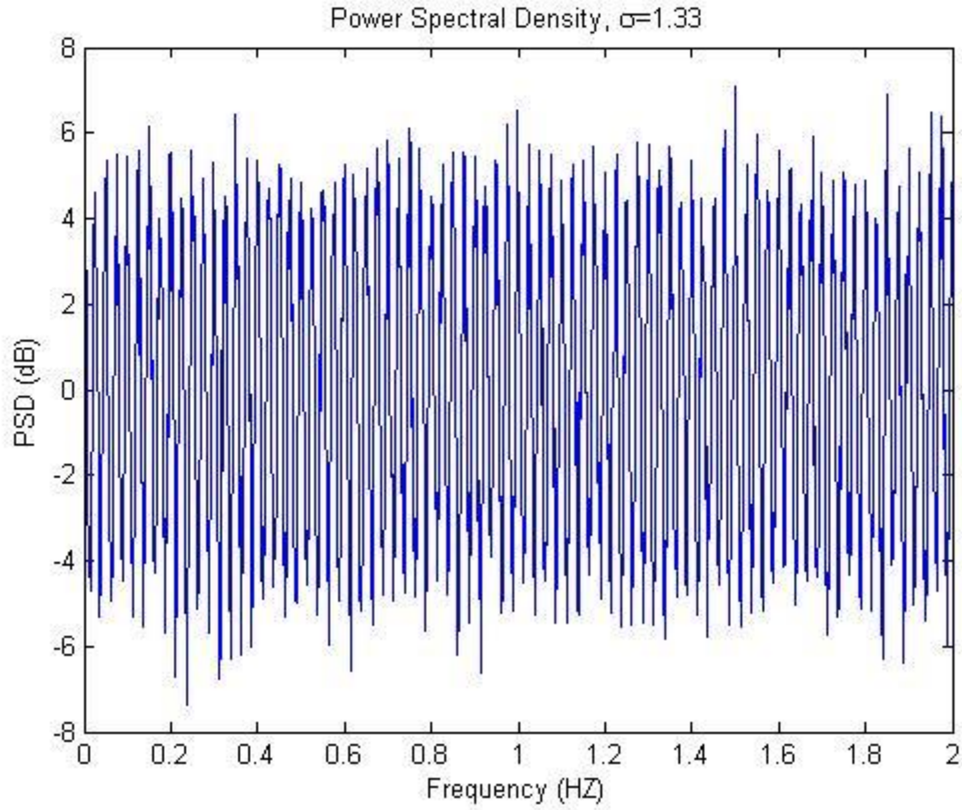

Figure 6. Power Spectral Density with SW AIC Sigma.

The new technique SW-AIC has been explored. We have seen that the interference rejection capability of individual SW-AIC technique is far better than previous techniques discussed in chapter 2 and chapter 3. This technique reduces the BER of the system and increases the throughput of the system. We have proposed a technique to control the BER of the system without affecting the notch depth, but slight reduction in throughput will be there. On the other hand SW-AIC is already equipped with a control mechanism to control both BER and notch depth in tradeoff manner, i.e. if factor improves then another factor have to scarify. The proposed scheme is easily extendable for getting better BER performance and throughput performance without sacrificing the notch depth. The only drawback we have to face is the increase in complexity of mathematical operations as we have to add two schemes here.

IV. CONCLUSION

In this thesis, we first present the overview of Orthogonal Frequency Division Multiplexing (OFDM) system. The architecture, advantages and disadvantages of this technique have been discussed. The OFDM based Cognitive Radio system has also been discussed. Further, in this thesis an attempt has been made at suppressing the interference generated due the sidelobes in the spectrum. The interference occurred from secondary users to the primary users of the spectrum resulting in sidelobes and its suppression techniques were discussed.
The two main and important existing techniques for sidelobe suppression discussed in this thesis are:
1.) Active Interference Cancellation (AIC) Technique
2.) Subcarrier Weighting (SW) Technique
In chapter 3 AIC and SW techniques has been explained.

We have discussed AIC scheme which can produce much deeper notch (approx. 30dB for 2 AIC edge tones). The mathematical formulation of this technique has been explained for conventional AIC technique. The impact on throughput and system performance is analyzed in AIC scheme. The notch depth in AIC technique highly depends on the input bit stream so more variation like AIC-cyclic, AIC-phase, and AIC-cyclic-phase have been discussed. The observed notch gain received is of 15dB, 15dB, 23dB respectively as compared to conventional-AIC. Increase in notch depth comes with an increase in OOB emission. The all AIC schemes were executed in MATLAB software and respective graphs have been shown. The graph results and simulation for AIC were also discussed. Based on these observations, we have drawn the drawback (throughput degradation) of this technique by comparing the results.

A Sidelobe suppression technique called Subcarrier Weighting (SW) is almost unexplored for inband interference cancellation. We have discussed the existing SW techniques for sidelobe suppression and its mathematical formulation. The implementation of SW technique in MATLAB is also given in this thesis. This report presents the importance of SW to protect NB systems. By analyzing the MATLAB results we can conclude that this scheme can produce variable depth (20dB to 50dB) of notch depending on the constraints on weights. Increase in notch depth comes to sacrificing the BER performance. We have proposed the SW-Rectangle variation in this report to improve the performance of the system. This scheme does not require any side information transmission at the time of sidelobe suppression and is capable of reducing the sidelobes of an OFDM system.

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