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Threshold Determination of SC-FDMA System using Resource Allocation

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Abstract –**Communication signals over power-line channels can be affected greatly by impulsive noise (IN). The effect of this noise is commonly reduced with the application of a nonlinear preprocessor at the receiver such as blanking or clipping that blanks and/or clips the received signal when it exceeds a certain threshold. Erroneous blanking/clipping of the unaffected signals can lead to significant performance degradations. It is found that determining the optimal blanking/clipping threshold is the key for achieving best performance. In contract to these studies, we show in this paper that the performance of the nonlinear preprocessing-based method is impacted by the blanking threshold. In light of this and for more efficient IN cancellation, this paper proposes single-carrier FDMA (SC-FDMA).**

Keywords –**FFT, OFDM, I-FDMA, L-FDMA, SC-FDMA.**

I. Introduction

The history of multi-carrier modulations began more than 40 years ago with a precursor system called Kineplex designed for military radio links in HF band (1.8-30 MHz). The use of the Fourier transform for modulation and demodulation was proposed for the first time by Saltzberg in 1967 and then by Weinstein et al. in 1971. Since perfectly orthogonal analog filters are expensive, this system has not been as successful as expected. It was not until the early 1980s that, using discrete modeling based on Fast Fourier Transform (FFT) digital modulators, multi-carrier modulations gain of interest this enabled the quasi-immediate take-off of this technology due to its low complexity. The fast Fourier transform calculation algorithm was invented by Cooley and Tukey, both engineers in the IBM research centre in the early 1960s. It has had a significant impact on the Development of applications in digital signal processing. A discrete Fourier transform calculation is a product computation of a matrix by a vector performed recursively. This reduces the complexity of the modulator and thus the consumption of the terminals. FFT-based multi-carrier systems are currently known as the Orthogonal Frequency Division Multiplexing (OFDM) for wireless networks or Discrete Multi-Tone (DMT) for wired networks, up to the SC-FDMA technique, which is Use the OFDM technique and DFT modulator [1].

II. Single-Carrier Modulation

Single-carrier transmission systems are systems that transmit data sequentially over a single frequency band or physical channel, around a single carrier, Figure 1.

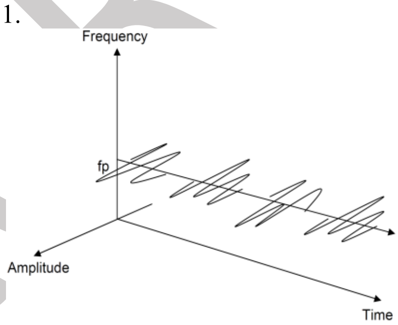

Figure 1: Single-Carrier Modulation [1]

This technique is certainly very simple to implement but have major disadvantages when we are in the presence of highly selective multi-path channels. Indeed the multiple paths of the channel introduce interference between symbols which affects the quality of transmission. This phenomenon is all the more accentuated as the symbol time of the system is low. To combat this degradation, estimation and equalization techniques exist in the literature, but these degradations can already be limited by adopting emission prevention measures as specific waveforms limiting the IES and which will be used as a physical medium for transmitting the signal. On the other hand, each symbol of this system, occupying all the communication bandwidth, will undergo the frequency selectivity of the channel. This phenomenon will be all the more likely as the bandwidth of the system is important, i.e. when the symbol time is low. In view of these two phenomena, it is easier to understand why this transmission technique is not adapted to new communication systems that require a larger bandwidth to carry more throughput. Thus, other more suitable transmission systems must be

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designed to withstand the current requirements in terms of flow [2, 3, 4, 5, 6].

III. Proposed Methodology

Figure 2 shows the block diagram for proposed research work. First, the information bits are mapped into baseband modulation symbols which are then grouped into blocks each with a length of Q symbols by the serial-to-parallel (S-to-P) converter $D_Q^a(n) = \{d_q^{n,a}\}, 0 \le q \le Q-1$. After that, these blocks are passed through a Q-point discrete Fourier transform (DFT) modulator to produce the frequency-domain representation i.e. $U_Q^a(n) = \{U_q^{n,a}\}, 0 \le q \le Q-1$.

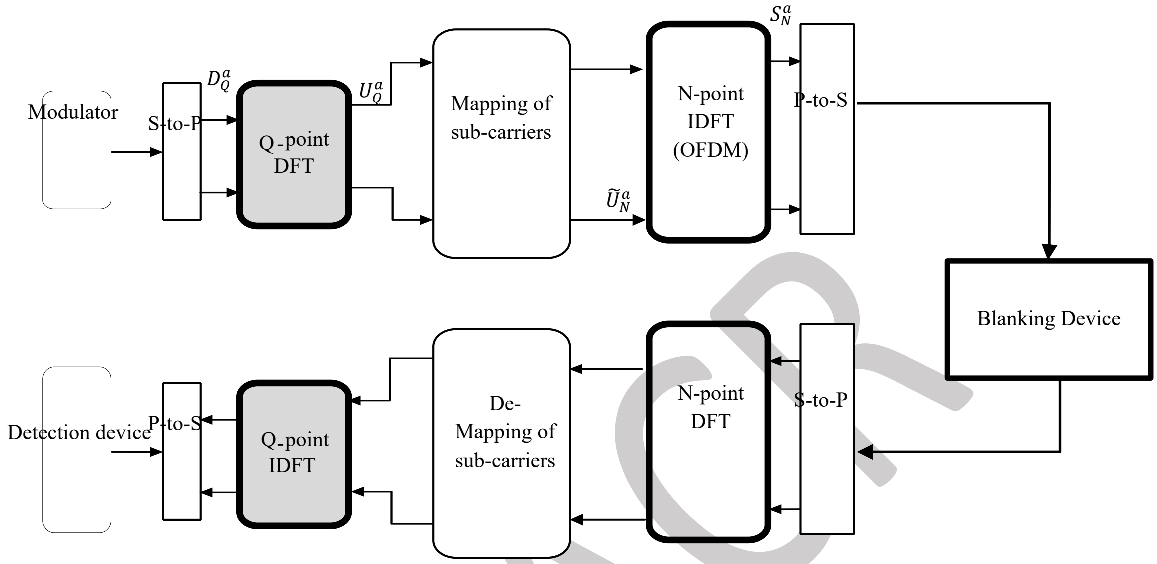
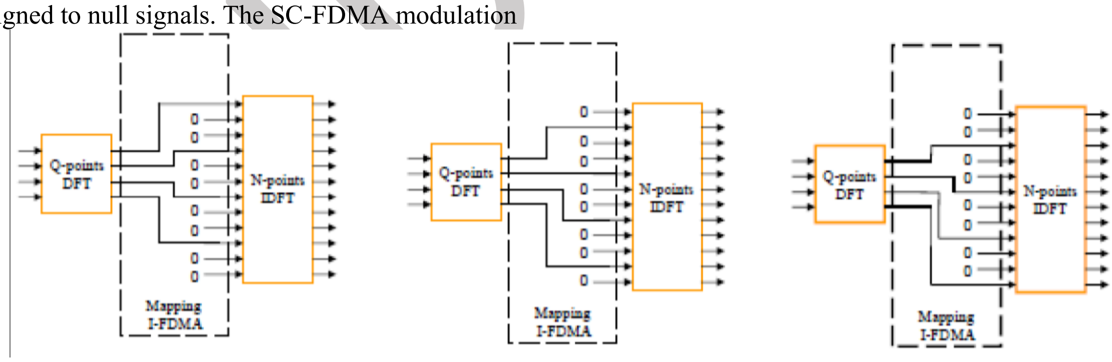


Figure 2: Block diagram for proposed work

Two modes of resource allocation exist for this modulation: Distributed Mode and Localized Mode.

Resource Allocation in Distributed Mode

In Figure 3, the unmodulated subcarrier $N-Q$ are assigned to null signals. The SC-FDMA modulation that uses this allocation mode is called IFDMA or ("Interleaved-FDMA").



(a) Terminal N°1 (b) Terminal N°2 (c) Terminal N°3

Figure 3: Mapping I-FDMA

Resource Allocation in Localized Mode

This is the localized mode which gives its name to the L-FDMA system or ("Localized FDMA"). This time the Q frequency symbols $\{U_Q^n = U_0^{n,a}, \dots U_{Q-1}^{n,a}\}$ corresponding to the output of the DFT modulator modulate a multiplex of Q contiguous subcarriers; The $N-Q$ other unmodulated subcarriers being assigned to null signals, Figure 4. Since the subcarriers are no longer distributed over the whole band of the system, one loses in frequency diversity. On the other hand, the system is more robust to the frequency offset by guaranteeing in this case the orthogonality of the signals of the various users.

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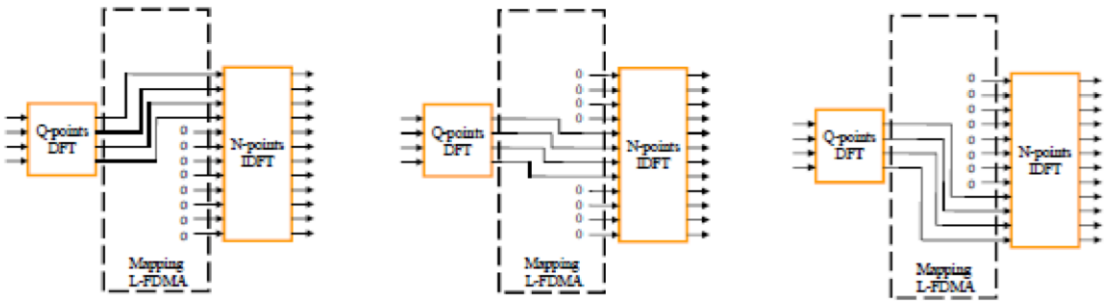

(a) Terminal N°1 (b) Terminal N°2 (c) Terminal N°3

Figure 4: Mapping L-FDMA

SC-FDMA Signal Analytical Expressions

In this part, we will adopt the notations indicated at the beginning of the document: $D_Q^a(n) = \{d_0^{n,a} \dots . d_{Q-1}^{n,a}\}$ will represent the block of symbols of the QAM modulation of the user a with $a \in [0 \dots, L-1]$. The frequency representation of the block $U_Q^a(n) = \{U_0^{n,a} \dots . U_{Q-1}^{n,a}\}$ obtained after the DFT modulation will be denoted by $D_Q^a(n)$. The spectral spread provides a signal at the input of the IDFT modulator given by $\tilde{U}_N^a(n) = \{\tilde{u}_0^{n,a} \dots . \tilde{u}_{N-1}^{n,a}\}$. The block SC-FDMA transmitted without consideration of the shaping filter or of the guard interval is denoted by $S_N^a(n) = \{s_0^{n,a} \dots . s_{Q-1}^{n,a}\}$.

Distributed Mode: I-FDMA

Mathematical description of the I-FDMA signal:

The discretization of the signal $s^a(t)$ of the user a at the output of the modulator SC-FDMA gives the sequence of symbols $\{S_k^{n,k}\} 0 \le k \le N-1$ obtained by the Inverse Fourier Transform (IDFT) of the block $U_N^a(n)$.

Since the block $\tilde{U}_N^a(n)$ is obtained by spectral spreading of the block $U_Q^a(n)$ of the user a, the relationship between the symbols $\tilde{u}_k^{n,a}$ and $u_k^{n,a}$ is given by equation (1).

$$\tilde{u}_k^{n,a} = \begin{cases} u_{(k-a)/L}^{n,a}, & s\,ik = L.q + a, (0 \le q \le Q-1) \\ 0 & sinon \end{cases} \tag{1}$$

$$S_m^{n,a} = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{u}_k^{n,a} e^{j2\pi\frac{m}{N}k},\ m \in [0, \dots N-1] \tag{2}$$

Since the total number of subcarriers N obtained with the spectral spread is higher than the number of subcarriers Q actually allocated to each user, each subcarrier can be indexed by $m \in [0 \dots N-1]$ as a function of Q and L as indicated in (3) with $L = \frac{N}{Q}$.

$$m = Q.l + p, \text{ with } p \in [0, \dots, Q-1] \text{ and } l \in [0, \dots L-1] \tag{3}$$

According to equation (3), the terms $\tilde{u}_k^{n,a}$ are zero except for $k = L.q + a$ where $0 \le q \le Q-1$. Thus since $N = Q.L$ the sum of the equation (2) can be simplified in (4) by considering only the terms in $k = L.Q + a$.

$$S_m^{n,a} = S_{Q.l+p}^{n,a} = \frac{1}{L}\left(\frac{1}{Q}\sum_{q=0}^{Q-1} u_q^{n,a}.e^{j2\pi\frac{qp}{Q_0}}\right).e^{j2\pi\frac{am}{N}} \tag{4}$$

In this equation we recognize an Inverse Fourier Transform of the $u_q^{n,a}$ symbols whose result is nothing but the source symbols of the constellation $d_p^{n,a}$ We also observe the appearance of a phase expression given by the vector $e^{i2\pi\frac{am}{N}}$ which is Specific to each user a. The signal at the output of the I-FDMA modulator can therefore be written as follows:

$$S_m^{n,a} = S_{Q.l+p}^{n,a} = \frac{1}{L}.d_p^{n,a}.e^{j2\pi\frac{am}{N}} \tag{5}$$

Where $l \in [0 \dots L-1]$ and $p \in [0 \dots, Q-1]$. A more condensed writing of this expression is given in (6). We thus deduce the mathematical expression of the I-FDMA signal as follows:

$$S_m^{n,a} = \frac{1}{L}.d^{n,a}{}_{m \bmod Q}.\Phi_m^a \text{ with } m \in [0, \dots, N-1] \tag{6}$$

Where $a = \left\{e^{j2\pi\frac{am}{N}}, m \in [0, \dots, N-1]\right\}$ is the phase rotation vector applied to the signal of user a. The mathematical expression of the signal I-FDMA which has just been established leads us to define a new method of generating the SC-FDMA signal without using the DFT and IDFT modulators as shown in the transmission chain. Indeed, the equation (6) makes it possible to write the symbols of the vector $S_N^a(n)$ in the following way:

$$S_N^a(n) = \{S_0^{n,a}, \dots S_{N-1}^{n,a}\} = \frac{1}{L}.\left\{\underbrace{[d_0^{n,a}, \dots, d_{Q-1}^{n,a}]}_{L\ time}\right\}.\Phi^a \tag{7}$$

Alternative method of generating the I-FDMA signal

The spectral spread introduced by the SC-FDMA modulation that we have allowed to widen the bandwidth of the signal of each user by a factor L with respect to that of the source signal, in order to

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be able to multiplex all the signals of Frequency users. Moreover, a spectral spread of order L is translated in the time domain by an operation of compression of the source symbols by the same factor L. The symbol time is reduced by a factor L making it possible to send, over a same duration, a number of symbols L times more important.

In view of the equation (7), and in the light of this remark, a new method of generating I-FDMA emerges. From a source signal $\{d_q^{n,a}\}0 \le q \le Q-1$ of a user a, the I-FDMA signal can be generated by simple compression of a factor L followed by a repetition by the same factor L after which a single phase rotation for each user to orthogonize the signals.

Localized Mode: L-FDMA

In this section we give a mathematical description of the L-FDMA signal.

Mathematical description of the L-FDMA signal

In the present case, the relation between the sequences of symbols $\tilde{u}_k^{n,a}$ and $u_k^{n,a}$ of the transmission chain is given by:

$$\tilde{u}_k^{n,a} = \begin{cases} u_q^{n,a}, & si\ k = Q.a + q, (0 \le q \le Q-1) \\ 0 & sinon \end{cases} \tag{8}$$

Taking the Inverse Fourier Transform of these symbols, we obtain the symbols $S_m^{n,a}$ of the output of the L-FDMA modulator given by:

$$S_m^{n,a} = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{u}_k^{n,a}, e^{j2\pi \frac{m}{N}k}, m \in [0, \dots N-1] \tag{9}$$

According to equation (8), the terms $\tilde{u}_k^{n,a}$ are zero except for $k = Q.a + q$ where $0 \le q \le Q-1$. Thus, since $N = Q.L$, the sum of equation (9) can be simplified in (10) by considering only the terms in $k = Q.a + q$:

$$S_m^{n,a} = \frac{1}{L}\left(\frac{1}{Q}\sum_{q=0}^{N-1} u_q^{n,a}\, e^{j2\pi\frac{mq}{QL}}\right).e^{j2\pi\frac{ma}{L}} \tag{10}$$

Moreover $m \in [0, \dots, N-1]$ implies that there exists $p \in [0, \dots L-1]$ and $l \in [0, \dots Q-1]$ such as $m = L.l + p$. Depending on the value of the parameter p, two cases occur:

When $p = 0$, equation (10) becomes:

$$S_m^{n,a} = S_{L.l}^{n,a}$$

$$= \frac{1}{L}\left(\frac{1}{Q}\sum_{q=0}^{Q-1} u_q^{n,a}\, e^{j2\pi\frac{(L.l)q}{Q.L}}\right)$$

$$= \frac{1}{L}\left(\frac{1}{Q}\sum_{q=0}^{Q-1} u_q^{n,a}\, e^{j2\pi\frac{lq}{Q}}\right)$$

$$= \frac{1}{L} d_l^{n,a} \tag{11}$$

In this last equation we recognize an Inverse Transform of Fourier of the $u_p^{n,a}$ symbols whose result is nothing but the source symbols $d_l^{n,a}$ see the chain of transmission. The signal at the output of the L-FDMA modulator for the present case can thus be written as follows:

$$S_{L.l}^{n,a} = \frac{1}{L}.d_l^{n,a}, \text{ with } l \in [0, \dots Q-1] \tag{12}$$

When $p \neq 0$, equation (12) develops as follows:

$$S_m^{n,a} = S_{L.l+p}^{n,a} = \frac{1}{L}\left(\frac{1}{Q}\sum_{q=0}^{Q-1} u_q^{n,a}.e^{j2\pi\frac{(L.l+p)q}{Q.L}}\right).e^{j2\pi\frac{(L.l+p)a}{L}} \tag{13}$$

The terms $u_q^{n,a}$ being the fourier transform of the source symbols, are given by:

$$u_q^{n,a} = \frac{1}{Q}\sum_{r=0}^{Q-1} d_r^{n,a}.e^{-j2\pi\frac{rq}{Q}} \tag{14}$$

Let's take $\Phi_p^a = e^{j2\pi\frac{(L.l+p)a}{L}} = e^{j2\pi\frac{ap}{L}}$. Equation (10) becomes:

$$S_m^{n,a} = \frac{1}{L}\left[\frac{1}{Q}\sum_{q=0}^{Q-1}\left(\sum_{r=0}^{Q-1} d_r^{n,a}.e^{-j2\pi\frac{rq}{Q}}\right).e^{+j2\pi\frac{(L.l+p)q}{QL}}\right].\Phi_p^a$$

$$= \frac{1}{L}\left[\frac{1}{Q}\sum_{r=0}^{Q-1} d_r^{n,a}\left(\sum_{r=0}^{Q-1} e^{-j2\pi\left\{\frac{l-r}{Q}+\frac{p}{N}\right\}\frac{rq}{Q}}\right)\right].\Phi_p^a$$

$$= \frac{1}{L}\left[\frac{1}{Q}\sum_{r=0}^{Q-1} d_r^{n,a}\left(\frac{1-e^{j2\pi\frac{p}{L}}}{1-e^{j2\pi\left\{\frac{l-r}{Q}+\frac{p}{N}\right\}}}\right)\right].\Phi_p^a \tag{15}$$

Thus, for $p \neq 0$ we have:

$$S_m^{n,a} = \frac{1}{L}\left(1-e^{j2\pi\frac{p}{L}}\right)\left[\frac{1}{Q}\sum_{r=0}^{Q-1}\left(\frac{d_r^{n,a}}{1-e^{j2\pi\left\{\frac{l-r}{Q}+\frac{p}{N}\right\}}}\right)\right].\Phi_p^a \tag{16}$$

In summary, the mathematical expression of the time signal TDMA is given below [2].

For: $m = L.l + p$, with $p \in [0, \dots L-1]$ and $l \in [0, \dots Q-1]$.

$$S_m^{n,a} = S_{L.l+p}^{n,a} = \begin{cases} \frac{1}{L}.d_l^{n,a} & if\ p = 0 \\ \frac{1}{L}\left(1-e^{j2\pi\frac{p}{L}}\right)\left[\frac{1}{Q}\sum_{r=0}^{Q-1}\left(\frac{d_l^{n,a}}{1-e^{j2\pi\left\{\frac{l-r}{Q}+\frac{p}{N}\right\}}}\right)\right].\Phi_p^a & if\ p \neq 0 \end{cases} \tag{17}$$

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IV. SIMULATION AND RESULTS

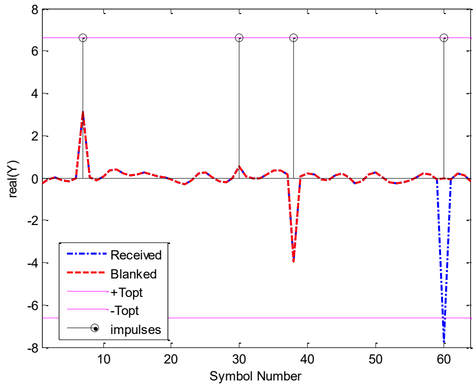

Figure 5: LFDMA blanking threshold

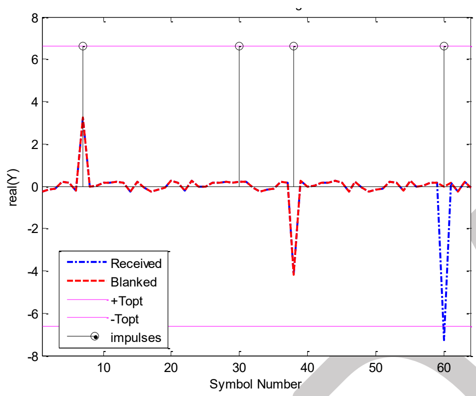

Figure 6: IFDMA blanking threshold

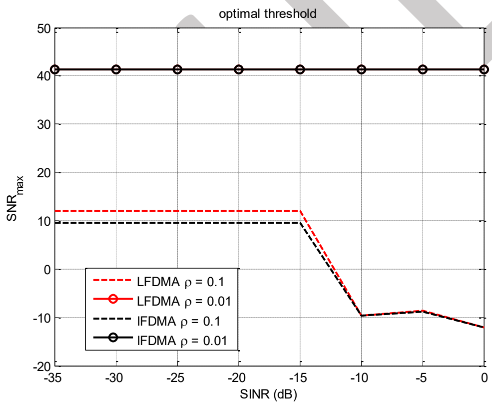

Figure 7: Optimal threshold

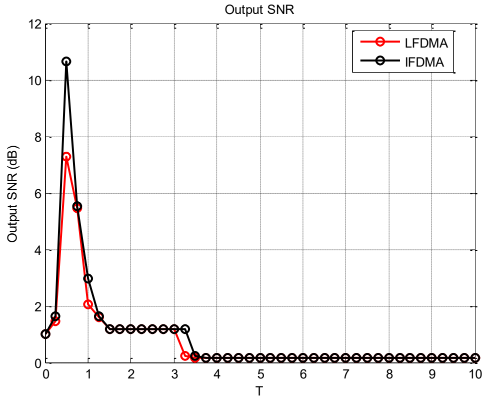

Figure 8: Output SNR

V. CONCLUSION

In this paper we have investigated the performance of SC-FDMA with blanking device at the receiver in the presence of impulsive noise. The results clearly show that the proposed technique is superior over the conventional OFDMA-based systems in the form of minimized probability of IN detection error and an increase in the output SNR which can be up to 4dB when blanking scheme is applied.

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