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Space-Time Coded Generalized Frequency Division Multiplexing in 5G Networks

[1]Dr.R.Suresh Babu, [2]B.Raveena, [2]S.Sriselvabharathi
[1] Associate Professor, [2] UG Student
Department of Electronics and Communication Engineering
Kamaraj College of Engineering and Technology, Virudhunagar.

ABSTRACT

The Next Generation of Wireless system will face different challenges from new services. Reliability is primary Foundation of Wireless network. We aim to improve the Symbol error rate (SER) which is the most aspect for future 5G Cellular network. In 2009, the initial concept of Novel Modulation scheme named Generalized Frequency division Multiplexing was proposed. Generalized Frequency Division Multiplexing is a Novel Filtered Multi Carrier Transmission Scheme that provides the Flexibility required by 5G applications. It's robustness against the Fading multipath environment can be increased by space time coding at the transmitter side when the receiver complexity kept minimal. A STC is a method used to enhance the reliability of data transmission in wireless network using more than one transmit antenna. Widely Linear Estimation is provided at the receiver side which jointly equalize and demodulates the Space Time Coded Generalized Frequency Division Multiplexing signal. Moreover Zero Forcing equalizer is used at receiver to detect the received signal and then the SER performance is evaluated in Rayleigh Multipath Channel. The performance is evaluated by comparing Coded Generalized Frequency Division Multiplexing and the conventional Orthogonal Frequency Division Multiplexing transmission in Frequency selective Fading channel.

Index Terms: Estimation, Modulation, GFDM, ZF equalizer.

I. INTRODUCTION

Mobile Communication has evolved as an important tool for the modern society. During the past decades, the evolution of mobile communication network has increased their capacity in terms of number of user and throughput. However, only higher throughput will not be enough to address future challenges foreseen for the fifth generation (5G) of mobile networks. Low latency has been important to trigger the new services. Latency means the delay between the input signals. This must be low for reliable communication. Besides low latency, low out of band emissions (OOB), fragmented spectrum allocation and relaxed requirements for synchronicity will be important in 5G systems.

In 4G Orthogonal Frequency Division multiplexing method is used. OFDM is the combination of modulation and multiplexing. This is the method of Digital communication that splits a wide bandwidth into small subcarriers using the Inverse Fast Fourier Transform (IFFT). These large numbers of the very closely spaced orthogonal sub-carrier signals are used to carry data on various parallel data streams. Each sub-carrier is modulated with an available modulation scheme at low symbol rate. The circularity introduced by a cyclic prefix (CP), which needs to be longer than the channel delay profile. Due to orthogonality of subcarriers, OFDM can be easily integrated with space time coding (STC) .OFDM is suited for frequency selective channels and very high data rates. This technique is transforms a frequency selective wide-band channel into group of non-selective narrow band channels, which makes it strong against large delay, spreads by conserving orthogonality in the frequency domain. It is easy implementation based on Fast Fourier Transform Algorithm. But the Application scenarios anticipated for 5G networks present challenges which OFDM can only address in limited way.

Despite its low composite implementation, easy application of transmit diversity scheme and well advanced theoretical background, OFDM is not acceptable for the 5G scenarios.MTC and machine-to-machine (M2M) communication require low power consumption, which makes the severe synchronization process need to keep the orthogonality between subcarriers unaffordable. The low latency needed for Tactile Internet and vehicle-to-vehicle applications demands for short bursts of data. It means that OFDM signals with one cyclic prefix (CP) per symbol would contribute a prohibitive low spectral efficiency. The low spectrum efficiency due to the insertion of the CP is also a problem for WLAN application. Additionally, the

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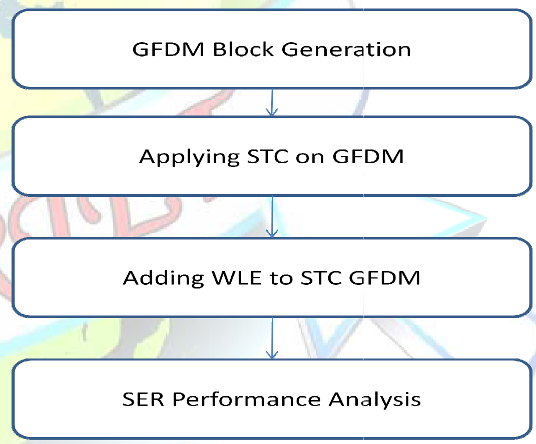
high out-of-band emission of OFDM poses a challenge for opportunistic and dynamic spectrum access. The inherent use usage of a rectangular pulse shaping filter requires enlightened techniques to attenuate the high OOB emission and makes its application in a fragmented spectrum scheme very problematic. Its high PAPR inhibits implementation of power efficient amplifiers. All these difficulties make OFDM not the most promising waveform for the next generation networks.

Generalized Frequency Division Multiplexing (GFDM) is an innovative concept that can be seen as a generalization of traditional OFDM. The scenario is based on the filtered multi-carrier approach and can offer an increased flexibility, which will play a significant role in future cellular application. Transmit diversity is a key feature for the next generation of mobile communication systems. The STC proposed by Alamouti is a simple solution to achieve this property. In previous works, time-reversal space-time coding (TR-STC) is shown as a feasible solution for GFDM, since the block structure of the signal in time domain allows the encoding of the waveform samples instead of the data symbols. This approach achieves full diversity gain and can be used as a frequency division multiple access scheme if a single guard subcarrier is used between multiple users. However, TRSTC-GFDM requires two GFDM frames to build the codeword. Although this approach presents a good performance in terms of symbol error rate (SER), it is clearly not optimal for low-latency applications. Christo Ananth et al. [4] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing. The proposed system has a fuzzy filter which has the parallel fuzzy inference mechanism, fuzzy mean process, and a fuzzy composition process. In particular, by using no-reference Q metric, the particle swarm optimization learning is sufficient to optimize the parameter necessitated by the particle swarm optimization based fuzzy filter, therefore the proposed fuzzy filter can cope with particle situation where the assumption of existence of “ground-truth” reference does not hold. The merging of the particle swarm optimization with the fuzzy filter helps to build an auto tuning mechanism for the fuzzy filter without any prior knowledge regarding the noise and the true image. Thus the reference measures are not need for removing the noise and in restoring the image. The final output image (Restored image) confirm that the fuzzy filter based on particle swarm optimization attain the excellent quality of restored images in term of peak signal-to-noise ratio, mean absolute error and mean square error even when the noise rate is above 0.5 and without having any reference measures.

GFDM is a favorable solution for the new 5G PHY layer because its versatility can address the different requirements. For real-time applications, the signal length must be decreased to fulfill certain latency requirements. Because GFDM is confined in a block structure of MK samples, where K subcarriers carry M sub symbols each, it is possible to design the time-frequency structure to match the time constraints flow latency applications. Different filter impulse responses can be used to filter the subcarriers and this choice influences the OOB emissions and the SER performance. As will be shown, GFDM allows engineering signals in their frequency and time characteristics.

Thus, the scenario retains all main benefits of OFDM at the cost of some additional implementation difficulty. In a GFDM block, the overhead is kept small by adding a single CP for an entire block that contains multiple sub symbols. This benefit can be used to improve the spectral efficiency of the system or it can be dealt for an additional cyclic suffix (CS), which allows relaxing the synchronization requirements of multiple users in an MTC scenario. Furthermore, all major synchronization algorithms made for OFDM can be adapted for GFDM. Of course, the latest technique multiple input multiple outputs (MIMO) will be a key feature in 5G networks. In this paper we show that space-time coding (STC) can be effectively combined with GFDM for achieving transmit and receive diversity.



The residue of this paper is well ordered as follows: Section II presents the principles of GFDM. Section III shows how STC can be applied and a linear demodulator is shown, while Section IV derives the WLE for STC-GFDM and analyses its complexity. Section V provides the SER performance analysis over frequency selective time-variant channels and, finally, Section VI concludes this paper.

II. GFDM BACKGROUND

In a GFDM block, N=MK data symbols are transmitted on K subcarriers. Each subcarrier is divided into M sub symbols. The complex-valued data symbols for one block are arranged in a matrix

$$D = (d_0 \quad d_1 \cdots d_{M-1}) \qquad \ldots (1)$$

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There, $d_m = (d_{0,m} \quad d_{1,m} \cdots \quad d_{K-1,m})^T$

Contains the K data symbols that are transmitted in the m^{th} sub symbol. Each symbol $d_{k,m}$ is transmitted on a waveform $g_{k,m[n]}$, which is derived from a prototype pulse shaping filter g[n]. The prototype filter is circularly shifted to the K^{th} subcarrier and m^{th} sub symbol, such that

$$g_{k,m}[n] = g[(n-mK) mod\ N] \exp\left(j2\pi \frac{k}{K} n\right) \quad \dots (2)$$

Where n=0, 1….N-1 is the time index usually, g[n] is a raised cosine (RC) filter with roll off. Accordingly, the Transmit signal x[n] is given by

$$x(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m} g_{k,m}[n] \quad \dots (3)$$

Eq. (3) can be formulated to an equivalent matrix expression

$$x = Ad \quad \dots (4)$$

Where the vector $x = (x[n])^T$ contains the samples of x[n]. d = vec (D^T) holds the rows of D transposed and stacked on top of each other. A contains $g_{k,m} = (g_{k,m}[n])^T$ as its (KM+m) th column. The above model can be extended to the case when only K_{on} subcarriers are switched on with K_{on} < K. In this case, the columns corresponding to the switched off subcarriers are removed from A. Furthermore, then matrix D is of dimension K_{on} ×M. A CP with length N_{CP} is added to the transmitted signal to avoid interference between subsequent GFDM blocks. Since only one CP is needed for all sub symbols, the CP overhead of GFDM is significantly reduced compared to OFDM.

III. SPACE-TIME CODE FOR GFDM

Transmit diversity is an important feature for mobile communication systems to provide robustness against frequency and time fading. Alamouti has proposed a simple and effective STC to obtain diversity in single carrier systems by using two transmit antennas without reduction of the overall data rate compared to single-antenna transmission .Alamouti's STC scheme is easily integrated with orthogonal multicarrier systems, but it is a challenge to apply this technique to non-orthogonal systems. The block diagram of the proposed STC transmitter is depicted. Let D_s contain all but the first column of D and let

$$D_s^{(1)} = [d_1 \quad d_2 \cdots d_{M-1} \quad d_{M-2}] = D_s \quad \dots (5)$$

$$D_s^{(2)} = [-d_2^* \quad d_1^* \cdots -d_{M-1}^* \quad d_{M-2}^*] = D_s^* P_s \quad \dots (6)$$

Be the space-time encoded data to be transmitted by the two Transmit antennas. There, Ps is given by

$$P_s = I_{\frac{M-1}{2}} \otimes \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \quad \dots (7)$$

Where I_n is the n×n identity matrix and ⊗ denotes the matrix Kronecker product.

IV. WIDELY LINEAR EQUALIZATION FOR STC-GFDM

In order to improve on the STC-GFDM performance, the multipath channel ISI needs to be equalized. This can be accomplished by jointly demodulating, equalizing and combining the received signal with the help of a widely linear estimator, where the block diagram of the processing chain is given in Fig. Widely linear estimation outperforms conventional linear estimation when either the estimation or the measurement is an improper process. The following section shows that the received signal is improper and the widely linear estimator for STC-GFDM is derived. Derivation of Widely Linear Estimators Mapping an i.i.d. bit sequence onto a rotationally invariant constellation with unit average symbol energy provides

$$E[d_s d_s^H] = I_{K(M-1)} \dots\dots\dots (8)$$

$$E[d_s d_s^T] = 0_{K(M-1)} \dots\dots\dots (9)$$

Where O_n is an n×n null matrix. Further, assuming the channel impulse responses between the transmit i^{th} and j^{th} receive antennas are invariant during the transmission of one GFDM block, which is reasonable for short block durations, the autocorrelation Γ (j) of r (j) is given by

$$r^{(j)} = E\left[r^{(j)} r^{(j)^H}\right] \quad \dots (10)$$

$$= \left[\hat{H}^{(1,j)} \quad \hat{H}^{(2,j)} P\right] \begin{bmatrix} \hat{H}^{(1,j)^H} \\ P^H \hat{H}^{(2,j)^H} \end{bmatrix} + \sigma_\omega^2 I_{MK} \quad \dots (11)$$

Similarly, the pseudo autocorrelation C (j) is given by

$$C^{(j)} = E\left[r^{(j)} r^{(j)^T}\right] \dots\dots (12)$$

$$= \left[\hat{H}^{(1,j)} \quad \hat{H}^{(2,j)} P\right] \begin{bmatrix} P^T \hat{H}^{(2,j)^T} \\ \hat{H}^{(1,j)^T} \end{bmatrix} \quad \dots (17)$$

Note that PPH = PPT = I. Since C (j) 6= 0, r (j) is an

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Improper (non-circular) process and WLE of d_s can improve the estimation performance. Compared to a linear estimator, a widely linear estimator jointly processes the received signal and it's conjugate to estimate the transmitted data by

BLOCK DIAGRAM

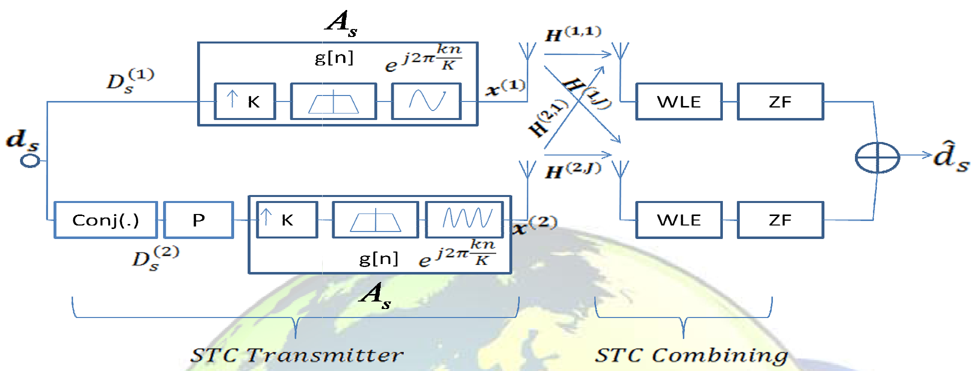

Figure: Block diagram of the proposed STC-WLE-Transceiver

$$\hat{d}_s^{(j)} = \begin{bmatrix} U^{(j)} \\ V^{(j)} \end{bmatrix}^H \begin{bmatrix} r^{(j)} \\ r^{(j)^*} \end{bmatrix} \quad \dots (13)$$

$$\text{Where} \quad \Phi^{(j)} = E\left[r^{(j)} d_s^H\right] = \hat{H}^{((1,j)}$$

$$\text{and} \quad \Theta^{(j)} = E\left[r^{(j)} d_s^T\right] = \hat{H}^{(2,j)} P$$

The solution of eqn (10) Is given by

$$U^{(j)} = S^{(j)^{-1}}\left(\Phi^{(j)} - C^{(j)} \Gamma^{(j)^{-1*}} \Theta^{(j)^*}\right) \quad \dots (14)$$

$$V^{(j)} = S^{(j)^{-1*}}\left(\Theta^{(j)^{-1*}} - C^{(j)^*} \Gamma^{(j)^*} \Phi^{(j)}\right) \quad \dots (15)$$

$$\text{Where} \quad S^{(j)} = r^{(j)} - C^{(j)} \Gamma^{(j)^{-1*}} C^{(j)^*} \quad \dots (16)$$

The filter coefficients U(j) and V(j) are chosen to minimize the mean squared error (MSE) between ds and^d(j)s and are solutions to the linear system

$$\begin{bmatrix} \Gamma^{(j)} & C^{(j)} \\ C^{(j)^*} & \Gamma^{(j)^*} \end{bmatrix} \begin{bmatrix} U^{(j)} \\ V^{(j)} \end{bmatrix} = \begin{bmatrix} \Phi^{(j)} \\ \Theta^{(j)^*} \end{bmatrix} \quad \dots (18)$$

V. SER PERFORMANCE ANALYSIS

An approximation for the SER performance over fading multipath channels for STC-OFDM [22] and STC-GFDM with QAM modulation and ZFR [6] is given by

$$p_e = 4\left(\frac{2^{\frac{\mu}{2}} - 1}{2^{\frac{\mu}{2}}}\right)\left(\frac{1-\varphi}{2}\right)^{2J} \times \sum_{u=0}^{2J-1} \binom{2J-1+u}{u} \left(\frac{1+\varphi}{2}\right)^u \quad \dots (19)$$

Where μ is the number of bits per symbol of the QAM constellation and

$$\varphi = \sqrt{\frac{3R_{CP}\sigma_{req}^2 E_s}{2(2^\mu - 1)\xi N_0 + 3R_{CP}\sigma_{req}^2 E_s}} \quad \dots\dots (20)$$

Is the equivalent average signal to noise ratio E_s and $N_0$are the average energy of the QAM constellation and the noise spectral density, respectively. R_{CP} is the rate reduction due to a CP with N_{CP} samples or vacant sub symbols and ξ is the noise enhancement factor (NEF).

Parameter	OFDM	GFDM

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R_{CP} ξ	$\frac{K}{K+N_{CP}}$ 1	$\frac{(M-1)K}{MK+N_{CP}}$ $\frac{1}{KM}tr(B_{ZF}B_{ZF}^H) \geq 1$

Table I: CP efficiency and NEF for OFDM and GFDM

These parameters take different values for STC-OFDM and STC-GFDM, as presented in Tab. The equivalent parameter for the multipath Rayleigh channel is given by

$$\sigma_{r_{eq}}^2 = \sigma_r^2 \sum_{i=0}^{I-1} h_i^2$$

Where h is the channel impulse response with length I and σ_r^2 The parameter of the Rayleigh distributed taps.

Table II: GFDM Configuration

Parameter	Symbol	Value
GFDM prototype filter	g[n]	Raised cosine α = 0:2; 0:75
Number of sub carriers	K	64
Number of sub symbols	M	9
CP length	N_{CP}	15
Mapping	—	16-QAM
Number of Tx antennas	—	2
Number of Rx antennas		1 or 2
Detector	J	ZF, WLE-ZF, low-cplx. WLE
Sampling frequency	f_s	5 MHz

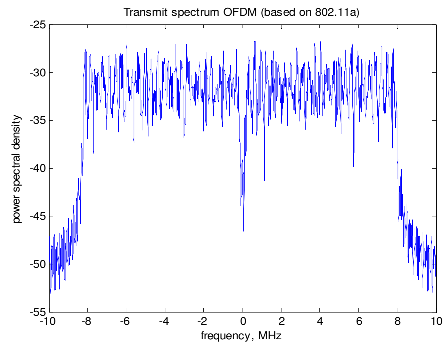

Figure 1: Transmit spectrum of OFDM

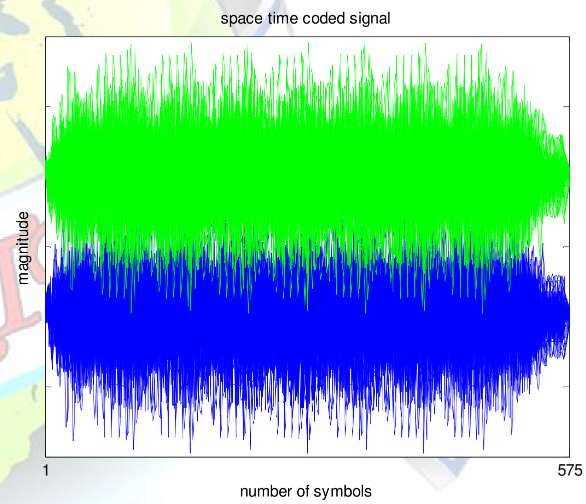

Figure 2: Space Time Coded GFDM

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Figure 3: Pulse Shaping Filter Output

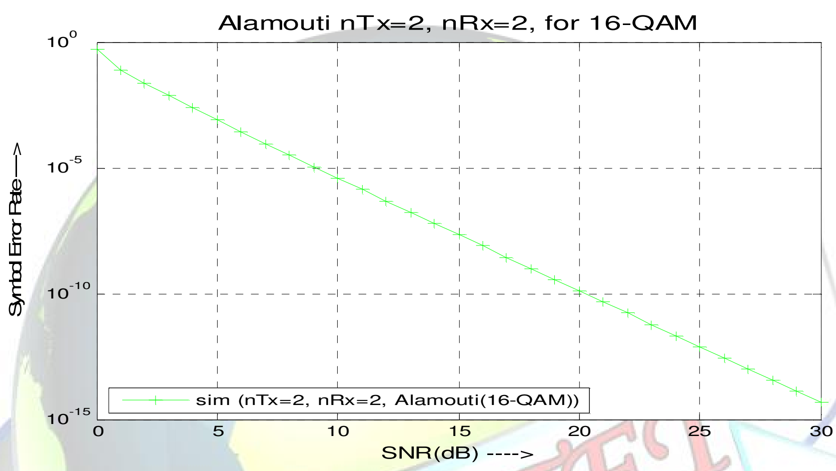

Figure 4: Simulated SER Performance of GFDM

VI . CONCLUSION

This paper has presented an advanced approach on demodulating a space-time encoded GFDM signal. Space-time encoding was carried out within a GFDM block in order to keep the overall system latency. This way transmit diversity can be achieved without increasing the physical layer latency compared to a single antenna transmission. At the receiver, the GFDM block is decoded with the help of a widely linear estimator which provides significant gains compared to previous works. The proposed scheme reaches nearly-optimal performance compared to OFDM, with slight degradations in high SNR regions (SER < 10□3). These deviations can be combated with forward error coding. The scheme can be combined with a MRC approach at the receiver where the symbols from the antennas are linearly combined after WLE has been carried out per antenna. This way, the matrix inversion complexity for the WLE is kept constant regardless of the number of receives antennas. The complexity analysis reveals that processing in the frequency domain allows the system to be solved with linear complexity in the number of subcarriers and is as such suitable for low-latency implementations.

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