METHOD FOR NOISE INTERFERENCE REDUCTION IN WIRELESS RADIO DATA COMMUNICATIONS USING THE MULTI-CARRIER PRINCIPLE

Boris Yosifov Ribov, LZ1BJR

Space Research Institute, Bulgarian Academy of Sciences, 6th Moskovska, 1000 Sofia, Bulgaria, phone: +359 887 261866, e-mail: ribov@developer.bg

Vesela Ribova

University of Plovdiv, department of Applied Mathematics, 24th Tzar Asen St., 4000 Plovdiv, Bulgaria, phone: +359 889 610352

For multimedia implementations, consider the more efficient and robust OFDM (Orthogonal Frequency Division Multiplexing). OFDM, sometimes referred to as multi-carrier or discrete multi-tone modulation, utilizes multiple sub-carriers to transport information in from one particular user to another. The benefits of OFDM are high spectral efficiency, resiliency to RF interference, and lower multi-path distortion. The orthogonal nature of OFDM allows sub-channels to overlap, having a positive affect on spectral efficiency. In this publication is presented a method to solve the frequency-offset problem in ODFM. Along with the frequency offset correction and synchronization this method improve the BER performance. This method is based on use of spread codes with good autocorrelation function. Here we also present the implementation of this method in a single chip wireless encoder.

Key words: IEEE 802.11, OFDM, Spread Spectrum, RF transmission, Encoder

1. INTRODUCTION

Interferences in wireless communications are common problem. A research [4] shows that simultaneously work of Bluetooth and IEEE 802.11 [6] gives significant packet loss of the devices worked on IEEE 802.11. That is why DSSS (Direct Sequence Spread Spectrum) [2] and CCK (Complementary Code Keying) [3] modulations are not steady enough than GFSK (Gaussian Frequency Shift Keying) used in Bluetooth. OFDM's high degree of spectral efficiency (Figure 1), resiliency to interference and multi-path distortion, and existing inclusions in the leading higher rate wireless LAN standards, provides a strong based for the development of newer broadband wireless networks.

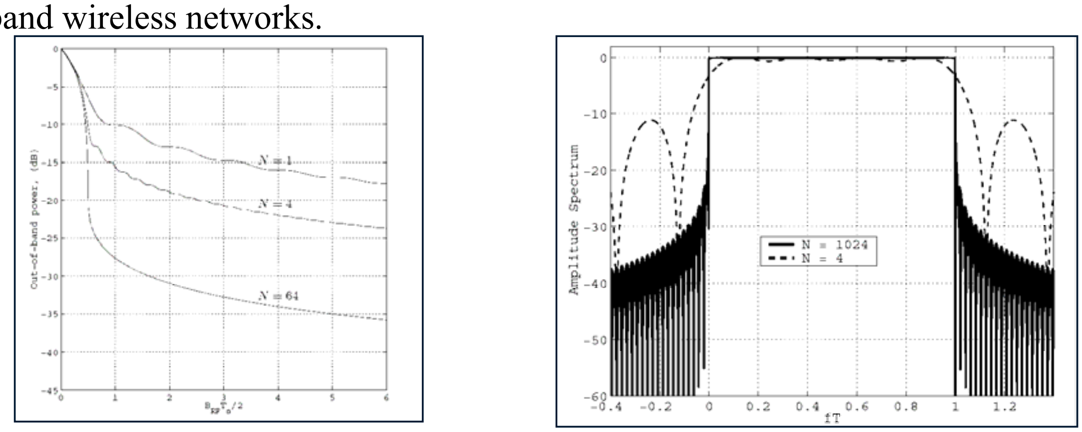

Figure 1 – Out-of-band efficiency

The technology is certainly proven; however, the future for OFDM is very bright as it gains significant momentum in the industry.

Still there exist two major problems to solve: One of the problems with OFDM is that the signal has a high peak power compared with its average power. When an RF carrier is modulated with an OFDM signal it results in a similar variation in power of the carrier envelope. This results in the requirement that the signal is amplified and transmitted in a linear way.

Other significant problem with OFDM is its sensitivity to frequency offsets affecting the performance. The demodulation of an OFDM signal with an offset in the frequency can lead to a high bit error rate. This is caused by the loss of orthogonality between the subcarriers resulting in inter-carrier interference (ICI), and a lack of correction for phase rotation of the received data vectors. Frequency errors will tend to occur from two main sources. These are local oscillator errors and Doppler spread. Any difference between transmitter and receiver local oscillators will result in a frequency offset. This offset is usually compensated for by using frequency tracking, however any residual errors result in a degraded system performance.

Movement of the transmitter or receiver results in Doppler shift in the signal. This appears as a frequency offset for free space propagation. This offset is usually corrected for as part of the local oscillator compensation. A much more serious problem is that of Doppler spread, which is caused by movement of the transmitter or receiver in a multipath environment. Doppler spread is caused by the different relative velocity of each of the reflected multipath components, resulting in the signal being Frequency Modulated. This FM modulation on the subcarriers tends to be random due to the large number of multipath reflections that occur in typical environments. This Doppler spread is typically poorly compensated for and results in degradation of the signal.

In a mobile multi-user environment the problem is worse, as the transmission from each user can have a different frequency offset. Even if each user is synchronized to the base station perfectly, there will still be significant different frequency offsets for each user due to Doppler shift. Frequency offset in a single user OFDM link isn't a significant problem as it can be compensated for with minimal increased receiver complexity. However in a multi-user case there is no easy way of correcting the frequency errors.

Here we present a method for compensation of frequency offset in a single user environment. Along with the frequency error compensation this method improves the BER performance as it increase the resistance in noise environments.

2. PRINCIPLE OT THE METHOD

The process of forming the spectrum is done in the transmitter. First the input data stream is converted from serial to 1024-bit parallel symbol. Thus we have 1024 parallel sub-channels to proceed at the same time but the bit-rate of every channel is 1024 times slower than the input data stream. Data coming from every cub-channel is combined with PN code (Pseudo Noise code) and the resulting bit-rate in every sub-channel increase by the spreading factor of the PN code. We use 13 bits for the PN code so the spread factor of the code is 13 [2]. In fact the spreading of the spectrum of every sub-channel increase the noise resistance of the method. The spreading PN codes have good autocorrelation function, so the receiver can extract clock synchronization and phase correction information from the received data.

After the data is spread it follows the process of orthogonal frequency generation for every sub-channel. We use codes generated from the rows of an orthogonal matrix (Figure 3) and the output stream from the transmitter is the momentary sum of all the combined orthogonal codes and the spread data for all of the sub-channels. The process is illustrated in Figure 2.

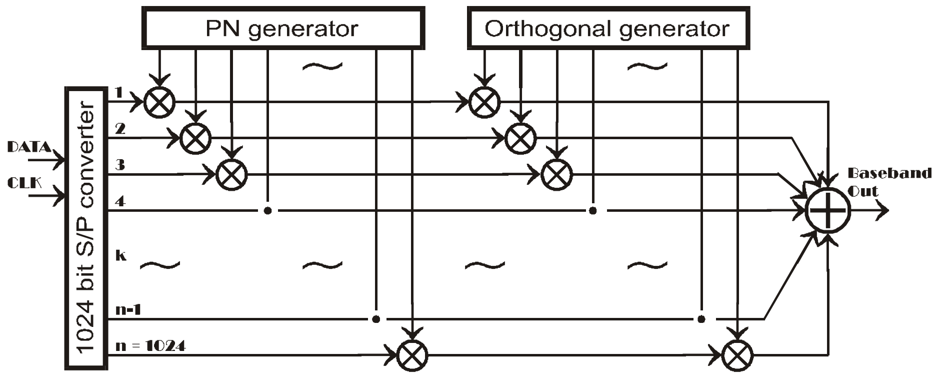

Figure 2 – Encoder block diagram

Here the clock rate of the PN generator is 13 times higher then the clock rate of the sub-channel data. The clock rate of the orthogonal generator is 1024 times higher than the resulting clock at the output of the spreading PN generator; that is 13312 times higher than the clock of the parallel sub-channels. The resulting clock rate at the baseband out is higher than the input data stream and the ratio is equal to the spread factor of the PN generator. In our implementation it is 13.

For data randomisation we use scrambling for every sub-channel. The scramblers are implemented directly at the output of the serial to parallel converter (S/P) to the every sub-channel. Scramblers are not shown on Figure 2. The scramblers (descramblers in the receiver) were added for two reasons: to provide a smooth link degradation in the case of multipath propagation and to drop the DC coupling requirement that complicates both FM and PSK transceiver design.

Now the most important problem is to generate the codes for the PN generator and the orthogonal generator.

3. MATHEMATICAL MODEL

In this publication we show a method for digital OFDM encoder different from traditional Inverse Fast Fourier Transformation (IFFT) to make OFDM channels. It is based on orthogonal matrices to form set of orthogonal sub-carriers.

A square matrix A is called an orthogonal matrix if it is equal to the inverse of its transpose, i.e. if $A=(A^T)^{-1}$. If an orthogonal matrix is real, then it is also a normal matrix. Walsh codes are subset of orthogonal codes based on orthogonal matrix.

Walsh codes can be obtained performing simple operations as it is illustrated in Figure 3. For the 2-ary case, taking a 2x2 matrix of 1s and inverting the lower right quadrant of the matrix form the basic symbols. To form the 4-ary case, take 4 of the 2x2 matrices and make a 4x4 matrix with the lower right hand quadrant again inverted. The procedure is repeated for the 8-ary case and beyond:

Figure 3 - Walsh matrix

Walsh functions have a regular structure and at least one member that have a substantial DC bias. In this case it is the first row with all 1s. All the rest are half 1s and half 0s. The DC bias can be reduced on the worst member of the set by multiplying all members with a cover code. This, however, introduces a (smaller) bias in half of the members.

Maximum length sequences (m-sequences), are PN sequences that repeat every 2^n-1, where '**n**' is an integer, they are implemented by shift registers and Exclusive OR gates, they are governed by primitive polynomials, and possess good randomness properties including a two-valued autocorrelation function.

For example the primitive polynomial generator governs the 7-chip PN sequence:

$$c_7(x) = 1 + x^2 + x^3 \qquad (1)$$

And the output chips are given by:

0 0 1 0 1 1 1 0 0 1 0 1 1 1 **0 0 1 0 1 1 1** 0 0 1 0 1 1 1 0 … (2)

Barker Codes are short unique codes (PN codes) that exhibit very good correlation properties. These short codes with **N** bits, with N=3 to 13, are very well suited for DSSS applications. A list of Barker Codes is tabulated in Table 1.

TABLE 1. BARKER AND WILLARD CODES

N	BARKER SEQUENCE	WILLARD SEQUENCE
3	**110**	**110**
4	**1110** or **1101**	**1100**
5	**11101**	**11010**
7	**1110010**	**1110100**
11	**11100010010**	**11101101000**
13	**1111100110101**	**1111100101000**

Willard codes, found by computer simulation and optimization, and under certain conditions, offer better performance than Barker Codes. A list of Willard Codes is tabulated in Table 1.

The inverted or bit reversed versions of the codes listed on Table 1 can be used since they still maintain the desired autocorrelation properties.

In our prototype we used 13bit barker sequences for the PN code (for the PN generator).

4. RESULTS

Design of the encoder is presented on Figure 4. We used FPGA – XC2S30 (Spartan II) [7] to implement the method. The spreading and orthogonal codes (total size is 13 Mbit) are stored in a high speed 64 Mbit SDRAM. The content of the SDRAM is initialised in the first time by subroutine running on the FPGA. The internal configuration is done by a loading program running at PC, connected to the encoder board by USB interface (FT2232C). After the initialisation of the SDRAM was done then the encoder is ready to receive data from the input interface. We provide two parallel ports for the purpose of high-speed data interface and complex communication protocol. The input communication can be done serial using some of the parallel interface pins by reconfiguration of the FPGA core. The baseband output is done by parallel 10-bit Digital to Analogue Converter (DAC). The design allows using a BitStream DAC for the future experiments. The use of 5 control leds helps for debugging and monitoring the communication process.

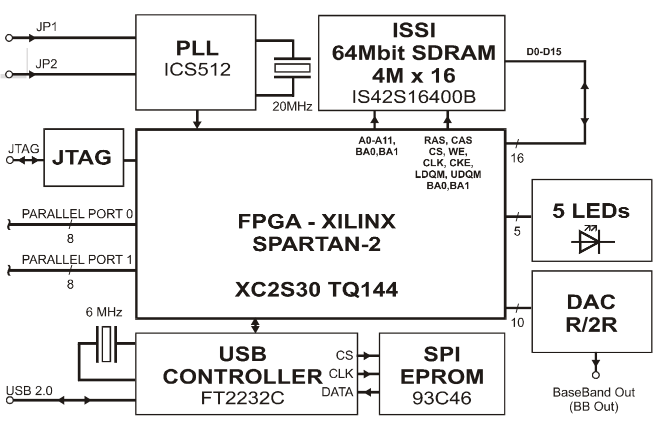

Figure 4 – Encoder

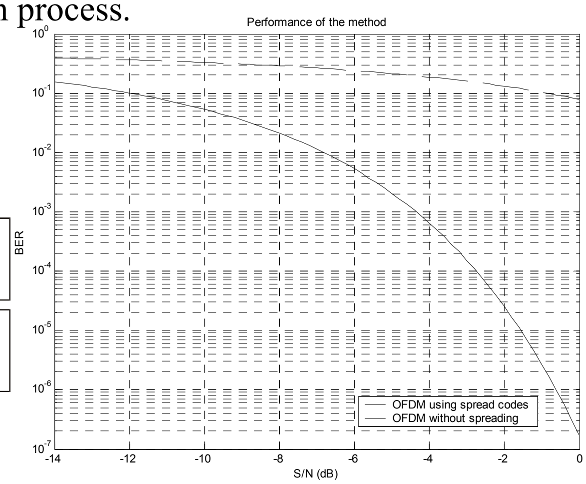

Figure 5 – BER performance

This method improves the digital radio communications in two major aspects. First it improves the S/N by 11dB. BER diagram of the experimental results is shown on Figure 5. The bold line corresponds to the performance of the presented method while the dash line corresponds to traditional OFDM transmission. The simulation also was done using MatLab [8].

The second aspect is the ability for clock synchronisation in the receiver. The spreading code used in transmitter has better autocorrelation properties. The receiver based on parallel correlation can extract phase correction information (see Figure 2) not only for the base clock correction (caused by oscillators drift); it also can extract information for correction of the clock for every sub-channel (it is important in Doppler correction, where the frequency shift is different for the lower and upper frequencies).

5. Conclusion and future work

Presented method and its implementation in a single-chip encoder resolve the problem with the frequency error correction in multi-carrier transmission methods, especially in OFDM [5]. The use of multi-carrier method promote for high multipath resistance in the high data rate transmission [1]. Implementation of correlation spreading codes for every sub-carrier contributes to high noise resistance and high resistance to the interferences from other transmitters using the same RF. BER (Bit Error Rate) improvement runs up to 11.1dB relative to noise and interference power.

The method is suitable in aerospace communications thus the more important issue is communication stability, also Doppler shift error compensation. Presented test bench relates to single user environment but it can be easy implemented in multi-user environment using the TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access) schemes.

Future work of this project is intended to integration of the method into the multi-user systems that use multi-carrier principle in multipath and noise environments. Also an investigation of ability to use FPGA for the implementation of the method in high-speed applications for the singe-user and multi-user mobile environment will be done.

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