KIET IJCE KIET International Journal of Communications &Electronics
Volume. No. 2, Issue No. 1, Jan – April 2014, ISSN: 2320 - 8996

Enhanced Performance of HF OFDM in Wireless Communication

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Abstract- **Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation technique for the broadband wireless communication system. In OFDM, the carriers are orthogonal to one another and multiple carriers share data among themselves, so it provides high spectral efficiency. The main advantage of this transmission technique is its robustness to channel fading. The main aim of this paper is to design and implement High Frequency (HF) OFDM communication system inorder to show that it provides better performance of the system compared to conventional OFDM communication system.**

Keywords- **HF OFDM, IFFT/FFT, Cyclic Prefix, PAPR.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a well-suitable modulation technique for wireless communications. Although OFDM came into being in the 1960s, only recently, it has been recognized as an outstanding method for high-speed cellular data communication. The modern digital signal processing techniques, such as FFT and IFFT are employed to implement the OFDM transceiver. OFDM can provide large data rates with ample robustness to radio channel impairments. OFDM transmits a great number of narrowband carriers, narrowly spaced in the frequency domain. The frequency selective fading and Inter Symbol Interference (ISI) effects due to multipath can be completely alleviated by employing OFDM in wireless communication systems. The flatness perceived by a narrow-band channel overcomes the frequency selective fading, and diminishes the ISI because when modulating at a very low symbol rate, the symbols become much longer than the channel impulse response. OFDM will provide more robustness against frequency selective fading when powerful error correcting codes together with time and frequency interleaving are used. Also, the effects of ISI can be effectively reduced by the insertion of an extra guard interval between consecutive OFDM symbols. This leads to avoid the use of an equalizer at the receiver. There are two major limitations in OFDM, viz., it is more sensitive to frequency offset and phase noise, and, it has a relatively large PAPR, which reduces the power efficiency of the radio frequency amplifier. These limitations can be eliminated by employing High Frequency (HF) OFDM communication system. Section II deals with the design and implementation of conventional OFDM as well as HF OFDM in wireless communication systems while section III discusses some applications of OFDM followed by a conclusion in section IV.

II. Design And Implementation Of Conventional Ofdm And Hf Ofdm Communication Systems

1. Conventional OFDM

Figure 1 shows the block diagram of conventional OFDM transmission system. OFDM is similar to Frequency Division Multiple Access (FDMA) except that OFDM uses the spectrum much more efficiently by spacing the channels much closer together, which is achieved by making all the carriers orthogonal to one another, thereby preventing interference between the closely spaced carriers.

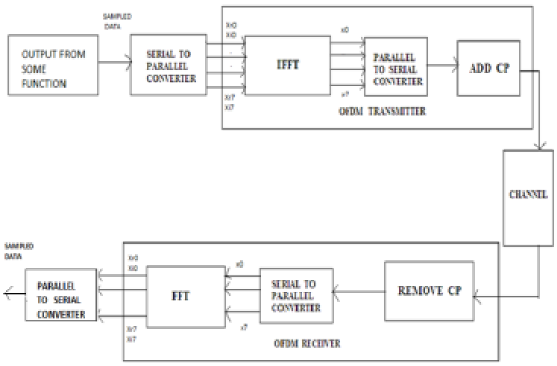

Fig. 1 Block diagram of conventional OFDM

OFDM splits the available bandwidth into many narrowband channels, each with its own sub-carrier. These sub-carriers are orthogonal to each other so that its spectrum has a null at the centre frequency of each of the other sub-carriers in the system, as shown in fig. 2. Linear Feedback Shift Register (LFSR) is used in the block diagram of figure 1 to give input to the OFDM transmitter.

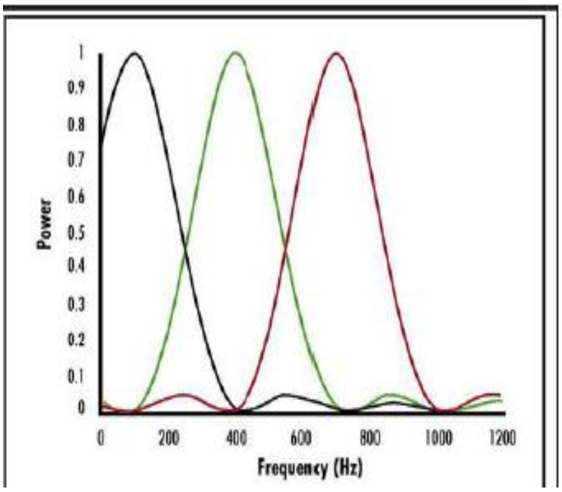

Fig. 2 Orthogonality of sub-carriers

A. IFFT

LFSR of length 16 is provided which is divided to form eight bits real and imaginary input for IFFT. The Inverse Discrete Fourier Transform (IDFT) of the sequence X(k) gives a sequence x(n) defined on the interval (0, N-1) as follows:

$x(n) = \frac{1}{N}\sum_{0}^{N-1} X(k)\, e^{j2\Pi k/N}$ ....(1)

Each of the N channel bits appears at a different sub-carrier frequency when signals at the output of IFFT are transmitted sequentially. By using an IFFT process, the spacing of the sub-carriers is chosen such that at the frequency where the received signal is evaluated, all other signals is zero. The IFFT/FFT algorithm is performed based on the eight-point DIT Radix-2 FFT butterfly structure as shown in figure 3. The parallel IFFT output is converted to serial using parallel to serial converter which is then fed to CP for removing the interference.

A. Cyclic Prefix (CP)

Cyclic Prefix (CP) are appended at the end of the symbol to eliminate the ISI from previous symbol. After performing IFFT and parallel to serial conversion operations, a cyclic redundancy of length v is added as a prefix such that

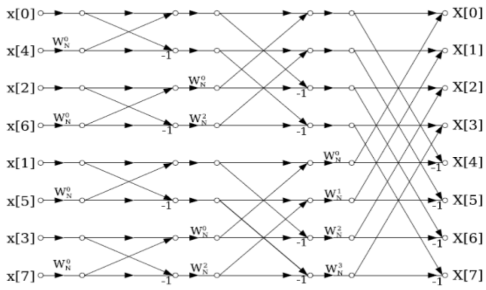

Fig. 3 Eight-point decimation-in- time FFT algorithm

$x_k(-i) = x_k(N - i)$ for i = 1, 2,..., v. ....(2)

CP added in the transmitter side will be removed after performing circular convolution with channel coefficients, and the resultant output is converted to parallel form using serial to parallel converter module, as the input to FFT should be in parallel form.

B. Fast Fourier Transform (FFT)

At the receiver, the exact inverse operation of transmitter is performed to recover the data. The data will be back in frequency domain after the FFT operation. The FFT should be always in the length of 2N. The equation for Discrete Fourier Transform (DFT) is

$X(k) = \sum_{n=0}^{N-1} x(n)\, e^{-j2\pi k/N}$ ....(3)

The computational time between DFT and FFT is faster using FFT method because the number of multiplications and additions operation in FFT is less compared to DFT method. Since serial data is to be transmitted, FFT output is converted back to serial format using parallel to serial converter.

The conventional OFDM system can be implemented using both MATLAB and FPGA. Field Programmable Gate Array (FPGA) is an example of VLSI circuit which consists of a sea of NAND gates. This hardware is programmable and the designer has full control over the actual design implementation without the need for any physical IC fabrication facility. This is the best choice for

OFDM implementation since it gives flexibility to the program design besides the low cost hardware component compared to others.

2. HF OFDM

The block diagram of a High Frequency (HF) OFDM communication system is illustrated in fig. 4. For decades, the HF band has been recognized as the primary means of long range wireless communications. In a multi-carrier HF system, the combination of OFDM with the Bit Interleaved Coded Modulation (BICM) is considered as the underlying physical layer platform. The design of HF OFDM is similar to conventional OFDM except that HF OFDM includes several key techniques such as channel coding/decoding, interleaving/de-interleaving, symbol mapping/de-mapping, windowing, DAC, ADC, up/down conversion, synchronization and channel estimation, in addition to IFFT/FFT, cyclic prefix and cyclic postfix. The operation of IFFT/FFT, cyclic prefix and cyclic postfix is same as that in conventional OFDM.

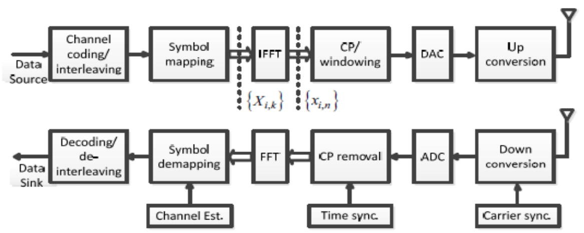

Fig. 4 Schematic of HF OFDM communication system

Interleaving is used in OFDM to attempt to spread errors out in the bit-stream that is presented to the error correction decoder, because the decoder is unable to correct all the bit errors when it is provided with high concentration of errors, and a burst of uncorrected error occurs. An efficient coding scheme can correct for the erroneous bits and thereby exploit the wideband channels frequency diversity. When error-correction coding is performed by an OFDM system, then it is known as Coded OFDM (COFDM) system. Symbol mapping is done to reduce the Peak-to-Average-Power Ratio (PAPR) which is a major drawback in OFDM systems. Digital to Analog Converter (DAC) is used to convert the digital data to analog form for up conversion. At the receiver, the inverse operation of the transmitter side is performed. Windowing is a well-known technique to reduce the level of side lobes and thereby reduce the signal power transmitted out of band.

A. *Time/Frequency Synchronization*

Synchronization is a key issue in the design of a robust OFDM receiver. Time and Frequency Synchronization are significant to identify the start of the OFDM symbol and to align the modulators and the demodulators local oscillator frequencies. Orthogonality of the sub-carriers is lost when any of these synchronization tasks is not performed with sufficient accuracy, thereby introducing Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI). The two HF OFDM symbols in the frame head, shown in fig. 5 of the designed system, are used for frame detection and time/frequency synchronization. The algorithms namely delay correlation and cross correlation are respectively utilized for these two HF OFDM symbols.

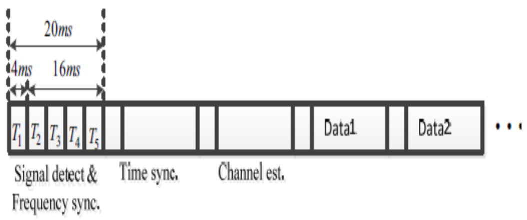

Fig. 5 Desired HF OFDM frame Structure

The delay correlation algorithm is based on repetition sequences and autocorrelation operation. If r(n) denote the received time sequences, then the delay correlation (d) at time point d can be expressed as

$$\Upsilon(d) = \sum_{n=d}^{d+L-1} r(n)\, r^{*}(n + N_{delay}) \quad \text{.............................(4)}$$

where N_{delay} denotes the delay length and L represents the sequence length of correlation operation, both having values 16 for the designed HF OFDM communication system. Due to 5 repetition sequences with length 16, 48 consecutive correlation peaks can be obtained. The normalized result can be obtained as,

$$d'_{dc} = argmax_d \left\{\frac{|\gamma(d)|}{\o(d)}\right\} \quad \text{... (5)}$$

where,

$$\o(d) = \frac{1}{2}\left\{\sum_{n=d}^{n=d+L-1} |r(n)^2| + \sum_{n=d}^{d+L-1} |r(n + N_{delay})|^2\right\}$$

....(6)

and d'_{dc} denotes the corresponding time points of correlation peaks.

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The original position of a radio frame can be approximately obtained by detecting the correlation peaks, and the frequency offset $\Delta f'_{dc}$ can be calculated in the range of $\left\{\frac{-N.\Delta f}{2N_{delay}}, \frac{N.\Delta f}{2N_{delay}}\right\}$ as

$$\Delta f'_{dc} = -\frac{\angle\gamma(d'_{dc}).N}{2\pi N_{delay}}\Delta f \quad \text{.......} (7)$$

B. Channel Estimation

Channel Estimation is required inorder to retrieve the data contained in the signal constellations. The third HF OFDM symbol in the designed system is assigned for channel estimation based on Least Square (LS) algorithm. Although the ISI caused by multi-path propagation can be effectively resisted by an enough long CP, the multi-path fading will still generate the scattering and distortion of the received signal constellation for each HF OFDM symbol. Due to multi-path fading, many signal constellation points will fall into an error adjacent decision region, that leads to serious system performance decline. Hence to avoid this, a suitable channel estimation method employing LS algorithm is used which in turn provides great improvement in system performance.

C. Peak-to-Average-Power Ratio (PAPR)

A simplest way of PAPR resistance is the clipping method which will cause nonlinear distortion of original HF OFDM signals. In general, an Error Vector Magnitude (EVM) is employed to define the caused distortion. The EVM of the i-th OFDM symbol is given as,

$$EVM_i = \frac{\sqrt{\frac{1}{N}\sum_{k=0}^{N-1}|X'_{i,k}-X_{i,k}|^2}}{|X_{i,k}^{max}|} \quad \text{.......} (8)$$

where $X'_{i,k}$ is the measured data constellation point relative to the reference constellation point $X_{i,k}$ and $X_{i,k}^{max}$ denotes the maximum constellation amplitude.

For each OFDM symbol, the signal peak will be clipped when PAPR is larger than a fixed threshold, which is equal to 6 dB for the designed system. In terms of this PAPR threshold, the distribution of 8PSK constellation points after the clipping operation is shown in fig. 6.

A. Bit Error Rate (BER) Performance

When no channel coding is used and assuming ideal synchronization is obtained, then the comparison of three modulation cases of QPSK, 8PSK and 16QAM is shown in fig. 7 in order to illustrate the performance of the designed HF OFDM communication system.

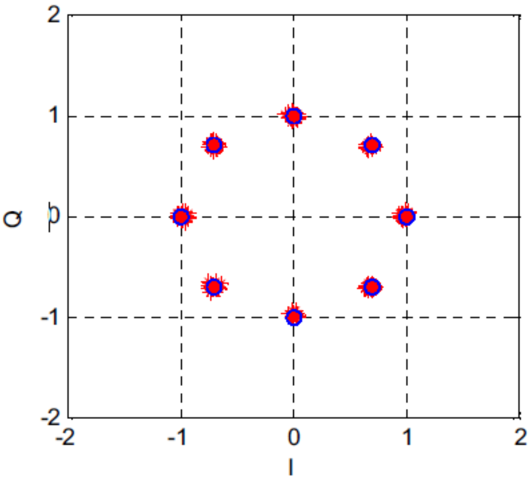

Fig. 6 The distribution of 8PSK constellation points after the clipping operation with 6dB PAPR threshold

When signal to noise power ratio achieves 25 dB, the BER of the designed system with 8PSK will be decreased to $10^{\wedge} - 4$. If a suitable channel coding is employed, better performance will be obtained.

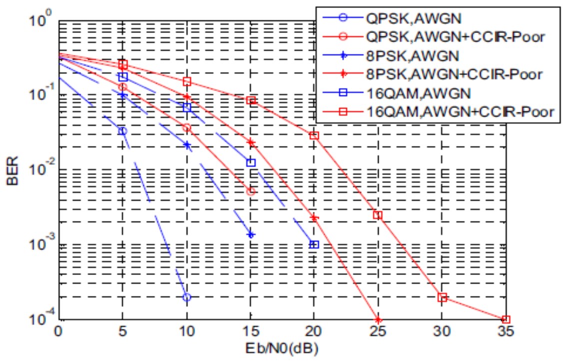

Fig. 7 Simulation of BER performance of the designed HF OFDM communication system

III. Applications

OFDM based wireless systems will provide the solution for future generation wireless communications. Multi-carrier techniques can combat hostile frequency-selective fading encountered in mobile communications. The robustness against frequency selective fading is very attractive, especially for high-speed data transmission.

OFDM scheme has matured well through research and development for high-rate WLANs and terrestrial DVB. Combining OFDM with CDMA yields synergistic effects such as enhanced robustness against frequency-selective fading and high scalability in possible data transmission rates.

Recently, wireless communication using white high brightness LEDs with OFDM is on the research process. Although high PAPR in OFDM is usually considered as a disadvantage in radio frequency transmission systems due to non-linearities of the power amplifier, high PAPR in OFDM can be exploited constructively in visible light communication to intensity modulate LEDs.

IV. CONCLUSION

The main purpose of the paper is to design a realizable HF OFDM communication system to overcome the drawbacks that has been observed in conventional OFDM communication system. We provide and discuss the parameters such as resistance to PAPR, time/frequency synchronization algorithm and channel estimation method. The BER simulation result shows that proposed HF OFDM system can achieve desirable performance.

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