A Review on Power Consumption Reduction Techniques on OFDM

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***Abstract*— Orthogonal Frequency Division Multiplexing (OFDM) modulation format is an excellent candidate for next generation networks due to its properties of high transmission speed, high spectral efficiency, and versatility. However, this technique does suffer from high power consumption caused by extensive signal processing and computational complexity. In order to solve this problem, many methods have been used such us Fast-OFDM, Dynamic Signal-to-Noise ratio (DSNR), Adaptive Cyclic Prefix (ACP), Adaptive Loading Algorithms (ALA), Asymmetrically Clipping Optical-OFDM (ACO-OFDM) and Asymmetrically Companded OFDM. In this paper, we review the aforementioned methods along with their advantages and drawbacks.**

Keywords— OFDM; Power consumption; Optical OFDM.

I. INTRODUCTION

Our modern way of living has created an incredible demand for resources that is damaging the eco-balance of our planet. In particular, due to the explosive growth of the Internet and the number of bandwidth-hungry services such as mobile networks, cloud computing, and high-resolution video, it is envisaged that the energy consumption of future networks will dramatically increase in the next few decades [1]. A simple solution towards a 'Greener' world is the reduction of the power consumption of electronic communication devices. In the next generation of networks, two of the most important factors will be energy efficiency and capacity management [2]

One of the most promising modulation techniques for next generation networks is Orthogonal Frequency Division Multiplexing (OFDM), due to its high capacity and flexibility, but it suffers from high consumption power due to complex Digital Signal Processing (DSP) operations [3]. FFT/IFFT (Fast Fourier Transform/ Inverse FFT) is one of the key operations in OFDM. Most power consumption in an OFDM transceiver is derived by IFFT/FFT operation. Various methods of reducing power consumption in OFDM have been develop addressing this problem have been developed in [4, 5, 6, 7, 8, and 9]. In Fast-OFDM, the IFFT/FFT blocks are replaced by the FCT/IFCT (fast cosine transform / inverse FCT) to enable not only twice the bandwidth efficiency compared to conventional OFDM but also to reduce the processing power by employing real arithmetic operations only, and single-quadrature modulation formats (such as Amplitude Shift-Keying). The Dynamic Signal-to- Noise Ratio (SNR) method uses variable length FFT/IFFT, which controls the precision of the processing calculation. The Adaptive Cyclic Prefix (ACP) method focuses on controlling the length of the Cyclic Prefix to eliminate fibre-link distortions in long-haul networks. Adaptive Loading Algorithms (ALA) methods focus on individual OFDM subcarriers by selecting the best modulation format (from Binary Phase Shift-Keying up to 256-Quadrature Amplitude Modulation, QAM) and by adjusting the optimum power per subcarrier. Asymmetrically Clipping Optical-OFDM (ACO-OFDM) and Asymmetrically Companded OFDM are two techniques that used to control the amplitude of the signal transmitted over a communication channel.

This paper presents a review of most important methods for reducing the DSP power consumption in OFDM. Most of them focus on processing operations described in section A and B such as Fast-OFDM and DSNR. In section C focuses on ACP by adding (Cyclic Prefix) CP, and section D focus on the ALA method for OFDM. Finally, section E and F is focuses on the ACO-OFDM and Asymmetrically Companded - OFDM techniques.

II. POWER CONSUMPTION METHODS

A. Fast OFDM

The main goals of next generation networks research are to reduce power consumption and increased network capacity. One of the most widely employed modulation schemes for this purpose is OFDM by means of IFFT/FFT as a basic operation. This part consumes a lot of DSP power when compared with other operations due to a large number of mathematical operations [5].

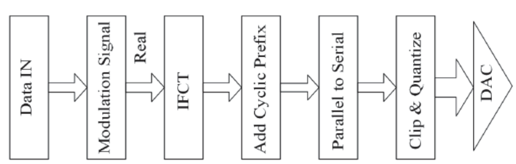

Fig. 1. Transmitter components of F-OFDM

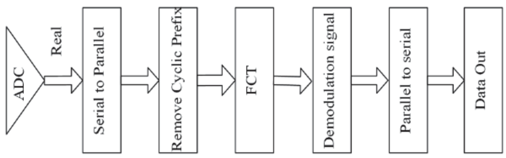

Fig. 2. Receiver components of F-OFDM

Related modulation techniques will be explained in the next section based on the IFFT/FFT but Fast-OFDM is based on IFCT/FCT (which replace the IFFT/FFT blocks) and has improved the bandwidth efficiency (twice the bandwidth efficiency) in comparison to conventional OFDM [10]. Consequently, Fast-OFDM can transmit more bits per channel compared to conventional OFDM because it reduces the frequency space between subcarriers. Other benefits include a reduction in DSP complexity, hardware components and operation time [11]. The most important feature in Fast OFDM is that its power consumption is reduced compared to conventional OFDM [12]. In figure (1-2) a typical block diagram of a Fast-OFDM (denoted as F-OFDM) transceiver is presented.

B. *Dynamic Signal to Noise Ratio (DSNR)*

There are many important factors in next generation network transponders. These include energy efficiency, network capacity, and flexibility. OFDM is one of the preferable modulation techniques for the next generation networks. However, it suffers from high energy consumptions due to complex Digital Signal Processing (DSP) operation in IFFT/FFT [13]. The number of inputs to IFFT/FFT depends on the number of sub-carriers used. A large number of sub-carriers increase the number of inputs to FFT/IFFT resulting in greater power consumption and the occupation of a large chip area [14]. The method which reduces power consumption by controlling the number of bits entering IFFT/FFT operations is named DSNR. The DSNR techniques control the calculation precision of the (FFT /IFFT) function of the DSP operation dynamically satisfying a Bit Error Rate (BER) requirement [15]. More specifically, this technique reduces the number of bits used in FFT/IFFT calculations resulting in a reduction in power consumption. The quantization and rounding error is used to control the calculation precision in the IFFT/FFT and manages the number of bits used in the OFDM frame generation [12]. Therefore, power consumption is improved by using the minimum number of bits while satisfying the optimum BER. In 2012, a research group from Japan worked on controlling the precision calculation of IFFT/FFT using DSNR to reduce the calculation in IFFT/FFT [5]. The block diagrams of the transmitter and receiver as shown in figure (3). This model includes Bit Length converter (BLC) to convert the symbol to a number of bits. The precision control uses to control the number of bits input to IFFT/FFT and select the minimum number of bits required for calculation result in a reduction in power consumption.

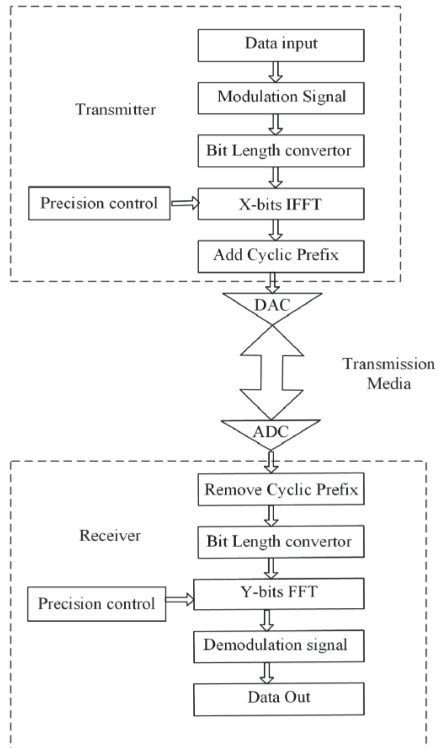

Fig. 3. OFDM Transceiver using Dynamic Signal to Noise Ratio.

C. *Adaptive Cyclic Prefix*

High-speed transmission can use a multicarrier modulation technique based on orthogonal carriers such as OFDM. If the distance between subsequent symbols is reduced, it can result in interference or overlapping of the OFDM symbols. However, inter-symbol interference (ISI) can be viewed also as a result of multipath propagation added after being transformed from a frequency to time domain by using IFFT [16]. However, the signal distortion and noise are increased due to overlapping. This effect is diminished by adding a cyclic prefix (CP) and fixing the distance between symbols. Adding a CP is performed by taking a copy of the last fraction of each symbol in the time domain and adding it to the front of the corresponding symbol to reduce the effect of the symbol overlapping or ISI, as in Figure (4). A cyclic prefix mechanism can be implemented by putting a gap between adjacent symbols and filling the gap using CP. The mechanism structure of CP is shown in Figure (5). There are two types of CP: fixed length type CP can be added between the symbols in the transmitter side after processing IFFT to extend the time domain period and it is equal size length between all the symbols. The other type is variable length CP [3].

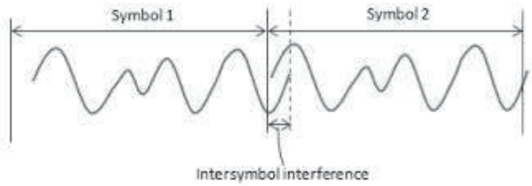

Fig. 4. Inter Symbol Interference (ISI) Structure [6]

A fixed type CP on OFDM increase the number of bits used in transmission and the variable length CP reduced the number of bits and consume less power when compared to fixed size CP [17]. In 2008, a group from Bangor University experimented on Adaptive Cyclic Prefix (ACP) [18]. They work on a variable length CP which depends on the receiver side BER, selected a length of CP that best satisfied the BER of the transmitted signal as shown in Figure (6).

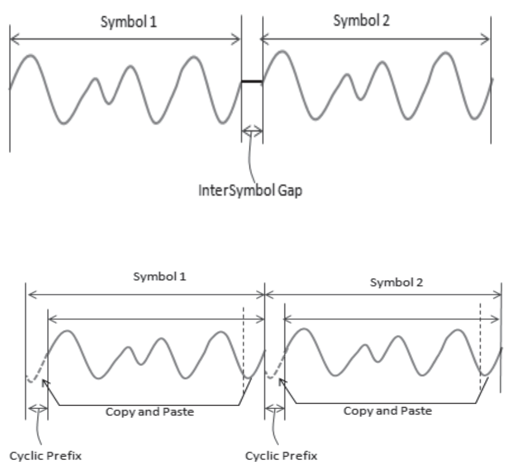

Fig. 5. Mechanism of Cyclic Prefix [6]

This method controlled the length of the CP by selecting the optimum BER on the receiver side and sending a feedback signal to the transmitter this controlling the CP length. In addition, ACP provides a reduction in the unused space of a CP and increases the bandwidth, resulting in an improvement of the transmission performance. A group in Italy also worked on ACP along with a bit loading (BL) algorithm, using a different modulation technique achieving a further reduction in terms of power consumption while improving SNR [19].

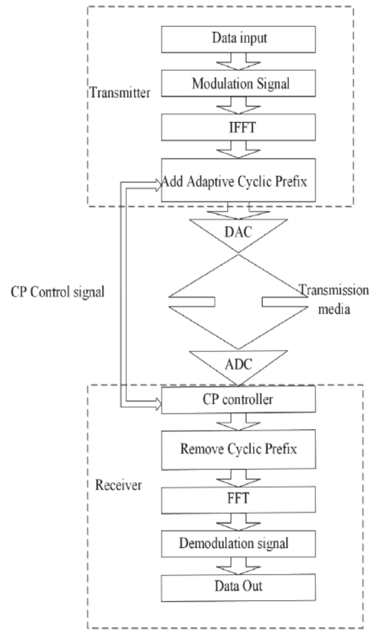

Fig. 6. OFDM Transceiver using Adaptive Cyclic Prefix

D. *Adaptive Loading Algorithm*

Improvements in the system flexibility and transmission performance along with in power consumption in OFDM can be achieved by increasing the utilization of each individual sub-carrier by applying various adaptive loading algorithms. The three types of algorithms are the following: BL (Bit Loading), PL (Power Loading), and BPL (Bit and Power Loading). Firstly, the Bit Loading algorithm means that the signal has identical signal power with a different signal modulation. This algorithm can control the number of bits per subcarrier depends on BER by optimizing the modulation format level. The BL algorithm occurs in frequency domain before modulation in the transmitter side, and then after demodulation in the receiver the Optical OFDM system enables the variation of the signal modulation format level for each individual subcarrier having identical power for all subcarriers [20]. This technique reduces the total energy consumption when compared without using BPL [21]. Secondly, a PL algorithm manipulates the electrical subcarrier power with the same modulation format for all sub-carriers [22]. Finally, a BPL algorithm adjusts both modulation and power for each subcarrier individually [23]. Although a large transmission bit rate can be achieved with the BPL algorithm, this algorithm suffers from high computational complexity in a transceiver due to complex FFT/IFFT mathematical operations. Transmission performance is usually best for BPL and worse for PL [7]. A diagram showing the interaction of the three ALA methods equipped with an OFDM transceiver is shown in Figure (7).

In 2010, the photonics group Bangor university conducted a Field-Programmable Gate Arrays (FPGA) experiment on a Multi-Mode Fibre (MMF) system channel using OFDM for short distances <800m [24]. They found that:

• BPL had the best transmission performance and PL has the worst.

• The transmission capacity difference between the BPL and PL algorithms that increases with both transmission distance and DAC/ADC sampling rate and is independent of the signal bit rate.

In 2011, a joint group from Photonics UK and AIT Greece investigated the optimization of an adaptive loading algorithm using Single Mode Fibers SMF system undertaken for distance <100km [25]. They have found that

• The transmission performance is best for
BPL and worst for PL.

• Transmission capacity differs between algorithms which is independent from the transmission distance and launched optical power. However, when employing large numbers of subcarriers with higher DAC/ADC sampling rate BPL should be adopted.

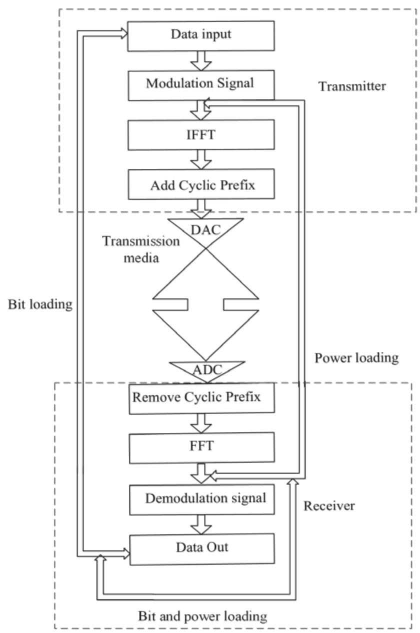

Fig. 7. Interaction of the three adaptive algorithm methods with an

E. Asymmetrically Clipping DC Bias Optical OFDM (ADO-OFDM)

To convert a signal from electrical to optical in OFDM data transmission over an optical channel, Intensity Modulation Direct Detection (IMDD) can be used. This technique uses only the positive real part of the signal because the intensity of light cannot be negative.

The most significant technique used to reduce power in IMDD is DC-bias Optical OFDM (DCO-OFDM). A DC current is added to the OFDM signal to make it positive in all the subcarriers carrying data [8]. The configuration of the DCO-OFDM transceiver is shown in Figure (8) using both real and imaginary parts of the signal. Another method is Asymmetrically Clipped (ACO-OFDM), which sets the negative parts of the signal to zero and a positive part carrying data. The imaginary part of the OFDM signal is set to zero using Hermitian symmetry shown in Figure (9). Dividing
the signal into two parts (real and imaginary), while the odd subcarriers carry data [26].

The ACO-OFDM method is more efficient in small constellations such as QAM (16, 32) than DCO-OFDM. However, DCO-OFDM is more efficient in large constellations using more power when compared to ACO-OFDM but it is efficient because of the two-part signal used instead of one [27]. These two methods above have been also implemented in real time FPGA [28].

Asymmetrically clipping DC Bias Optical OFDM (ADO-OFDM) combines aspects of both AC-OOFDM and DC-OOFDM [29] and uses even and odd subcarriers to carry data. The odd subcarriers are modulated by ACO-OFDM and the even subcarriers are modulated by DCO-OFDM [30] as it is shown in Figure (10). This technology improves the spectral efficiency of ACO-OFDM and power efficiency of DCO-OFDM improving BER and SNR of the transmitted signal [9].

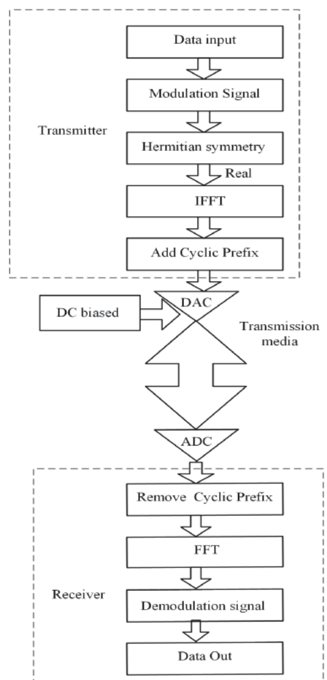

Fig. 8. DC-OOFDM Transceiver

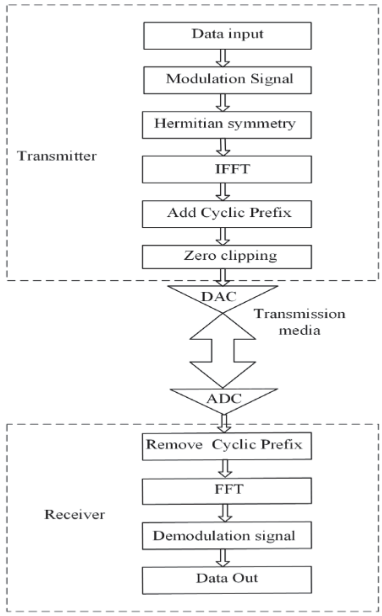

Fig. 9. ACO-OFDM transceiver

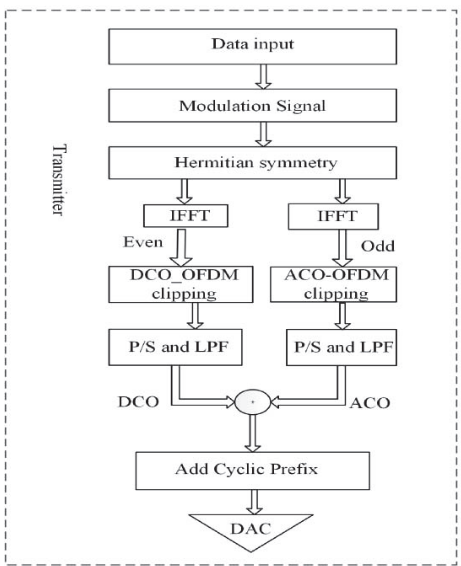

Fig. 10. ADO-OFDM transmitter

F. *Asymmetrically Companded DCO-OFDM*

IMDD uses only the real positive part of a signal. A theoretical technique proposed by a French group has the potential to reduce the power consumption in DCO-OFDM. The procedure of this method focuses on compressing the negative part of the bipolar real OFDM signal, which means reducing the negative peaks of the signal and then adding DC-Bias to the signal [31]. The amount of remaining negative peak is reduced so less amplitude affected by clipping. In the receiver side DC-bias and CP is remove then inverse companding transform (expander) applied to expand a compressed transmitted signal. The configuration system companded DCO-OFDM is described in figure (11). This technology can reduce the Peak Average Power Ratio (PAPR) in a transmitted optical OFDM signal, increases the bit rate and significantly reduces the complexity of the system [32].

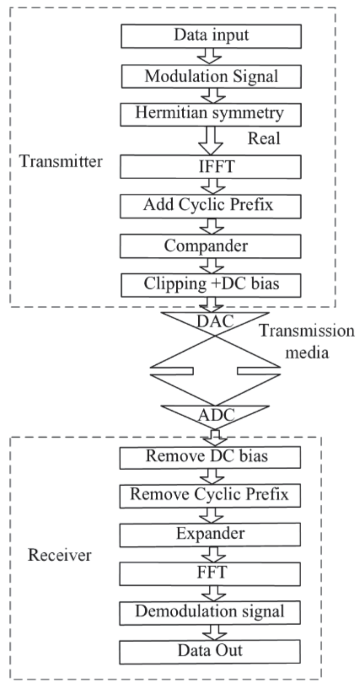

Fig. 11. Configuration system of Compand DC-OFDM

CONCLUSION

One of the main goals for next generation networks is reducing the power consumption, and various power-efficient multi-carrier modulation schemes have been described in this paper. In Fast-OFDM a FCT/IFCT is used instead of FFT/IFFT, while other methods exist such as DSNR to control the length of IFFT/FFT or by clipping/compressing a part of the signal such as in ACO-OFDM, DCO-OFDM, ADO-OFDM and Companded DCO-OFDM. Other methods control the length of the spectrum such as the Adaptive CP, which controls the length of the CP added between adjacent symbols Finally, ALAs can control the power and modulation for each subcarrier individually such as the BPL with high complexity but high performance or the PL algorithm with low complexity but low performance.

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