Study of UFMC outdoor Visible Light Communication systems with realistic LED radiation patterns and comparison with OFDM

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Multicarrier modulation techniques are gaining popularity in Visible Light Communication (VLC). Orthogonal Frequency Division Multiplexing (OFDM) is the most widely used for now. However, other candidates are emerging to optimize Optical Wireless Communication (OWC) further. This paper proposes a study and comparison in VLC of the theoretical use of OFDM and a new waveform called Universal Filtered MultiCarrier (UFMC). In such systems, a LED (Light Emitting Diode) is used as an emitter and a piece of photosensitive equipment as a receiver of the optical signal. As OFDM and UFMC are modulation schemes developed for Radio Frequency (RF) technologies, adaptations are needed to send the desired data through light. The two main constraints are the need for a real and positive electrical signal converted to light intensity variations. The present work highlights several manners to respect these constraints and the general architecture of the simulation. On top of the use of UFMC, the originality of our paper is the use of realistic LED optical spatial distributions and photodiode models to conduct the simulations. Finally, the paper discusses the system's performance in terms of Bit Error Rate (BER), spectral efficiency, and complexity of the algorithm.

Introduction

In the scope of smart cities and urban connectivity, it is slowly getting to a saturation point where urban Wi-Fi is not sufficient to provide high quality connectivity to the citizens [1]. One of the new technologies arriving in the communication technology spectrum is Visible Light Communication which has the advantage of delivering high data rate in specific areas. This could locally relieve the RF spectrum constraint. The high data rate utilization of VLC has the name Li-Fi and enables the end user to get internet connectivity. Within the development of Li-Fi standards, the main one (G.991) [2] proposes internet connectivity and uses OFDM as the main waveform. OFDM is a method of coding digital signals by orthogonal frequency division in the form of multiple subcarriers. This technique combats frequency selective channels by allowing low complexity equalization. Unfortunately, OFDM suffers from the drawback of high Out-Of-Band (OOB) spectrum and the necessity of wasting some useful capacity due to the usage of the Cyclic Prefix (CP). In the RF world, one of the waveforms that overcomes this problem is Universal Frequency MultiCarrier (UFMC) technology. It is also part of the waveform candidates for the upcoming 5G era. This work investigates the gain of using UFMC compared to OFDM for VLC systems.

On the one side, OFDM is the multicarrier modulation used in many wireless communication systems like LTE, 5G, DVB-T2 and VLC. On the other side, UFMC is the filter-based waveform proposed for 5G to fulfill the requirements of short burst communications. Indeed, due to the filtering operation performed per sub-band, its spectral selectivity can be modified such that the OOB emission is reduced. Like OFDM, UFMC is also based on Fourier transform operation but does not require the addition of a Cyclic Prefix (CP) to deal with Inter Symbol Interference (ISI). This makes the UFMC waveform spectrally more efficient than OFDM.

In comparison with the development of UFMC and OFDM technologies for RF (Radio Frequency), it is important to modify them to make them compliant with visible light communications. Indeed, while in the RF domain it is possible to work with the amplitude and phase of a data carrier, this is not the case in visible light communication as the incoherent nature of the LED does not allow the use the phase of the light to send information. IM/DD (Intensity Modulation/ Direct Detection) technique is therefore used to encode the information. The adaptation to VLC leads then to a transformation of paradigm from a complex signal with phase and amplitude to information encoded only in the positive real part of the signal. This real-valued signal then shapes the current of the LED in IM/DD to change the light intensity at the rate of the information. There are several strategies in the literature for rendering a real signal from a complex signal [3]. The most common technique is the application of the Hermitian symmetry property before applying the inverse Fourier transform (IFFT). This technique requires the duplication of the data vector by juxtaposing the useful signal and its inverted conjugate complex with the addition of two zero values at the beginning and at the half of this new vector. Then passing it through the inverse Fourier transform gives a real signal. This is the method used in the standard G.9991 for VLC OFDM but it is much more complicated to be applied to UFMC because of the filtering stage present in this technique. Therefore, the juxtaposition technique is preferred for UFMC and gives the desired result. The principle of this technique is to juxtapose the real part and the coefficient of the imaginary part to generate a real signal. At the reception, it is necessary to recover these coefficients respectively in order to reconstruct the symbol sent. Once the real signal is generated, it is sufficient to apply a constant shift value to the whole signal, namely a bias. The critical condition of this bias is that it must sufficient to make the whole signal positive. That is, it must worth at least the peak value of the signal to be transmitted.

To study these modulation techniques, a two-part simulator is used. The first part models the communication channel according to the system’s configuration. This configuration considers the location of the light transmitter in relation to the receiver, the presence of walls and calculates the spatial distribution of the light power [4]. To make the simulations as close to reality as possible, a urban scenario is chosen which includes a user under a street lamp hung on a house wall. The characteristics of the lamp are retrieved from a database of suppliers providing real lamp measurements in dedicated files. This first part simulator tool allows to collect the spatial attenuation incurred by the emitted signal. Then, the second part of the simulator focuses on the end-to-end communication aspect according to specific modulations and parameters such as the number of sub-carriers and sub-bands [5]. The calculations of Bit Error Rate and spectral efficiency are then performed.

The present work presents the comparison of OFDM with UFMC performance for VLC communication. First the system’s architecture is presented for both multicarrier technologies and is followed by the presentation of the simulation results. Finally, a conclusion is drawn on the best waveform’s choice strategy for VLC.

System architecture

In OFDM and UFMC, the input data are complex symbols resulting from a IQ symbol mapping method. OFDM is based on two main blocks: Inverse Fast Fourier Transform (IFFT) and CP insertion in emission. At the reception side, the reverse operations are applied. As in VLC system, real and positive values are transmitted, two techniques are used to get real symbols after IFFT: the Hermitian symmetry and juxtaposing techniques. In this simulator, the second technique has been chosen : a Direct Current (DC) bias is added to real symbols to make them positive as shown on Fig. 1. As the filtering operation in UFMC is done per sub-band, the data are subdivided into sub-bands (cf Fig. 2). Data of each sub-band undergoes IFFT operation, and the Chebyshev filter (of length L) is applied in time domain on each sub-band. In the case of the Juxtaposing technique, a zero-padding technique is applied on each received symbols of length $(N+L-1)$ at the receiver side to reach a sample number equals to twice ($2N$) the subcarriers number N used at the emission. This operation is followed by the Fast Fourier Transform (FFT) and the down sampling technique for data recovery.

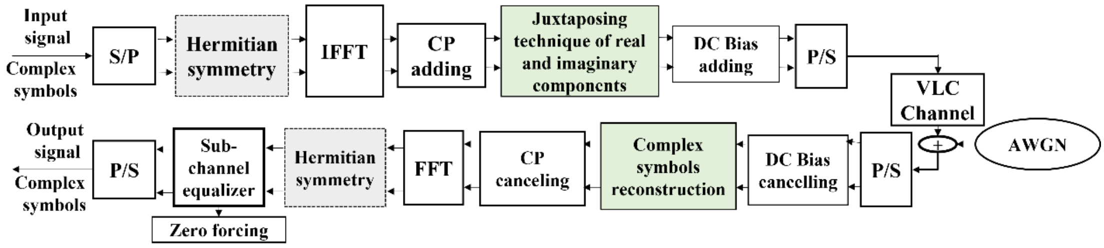

Figure 1: OFDM block diagram including Hermitian symmetry or juxtaposing technique

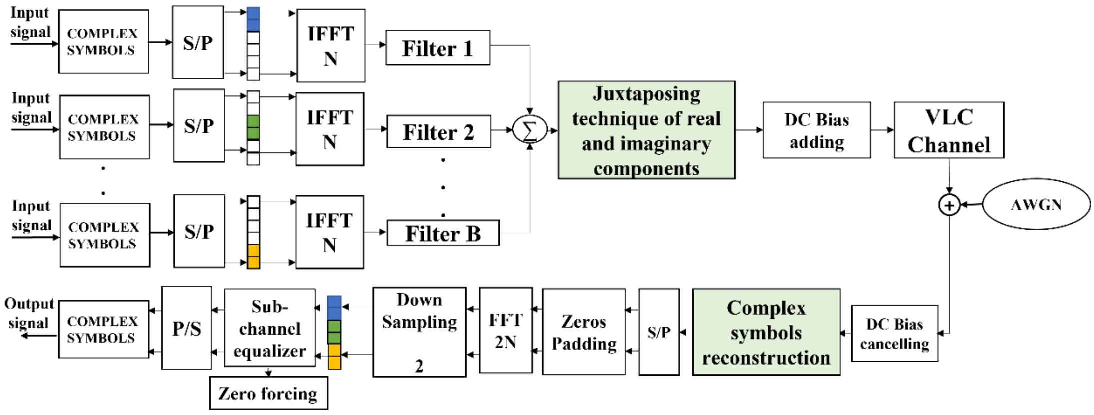

Figure 2: UFMC block diagram including juxtaposing technique

Results

This section presents the simulation results for the most encountered use case. The user is positioned under a streetlight of 6m high and the end-device is at a height of 1.5 m. The first part of the study is the comparison of both techniques to make the signal real for OFDM. Secondly, the comparison of UFMC and OFDM performance is shown. The parameters for OFDM come from the standard G.9991 for 256 subcarriers [2]. The parameters for UFMC were then adapted to have a similar base of comparison. The number of effective subcarriers is N 256, 21 sub bands of 12 subcarriers and a filter length L of 19 are used. A thousand symbols were generated to have the following results. Fig. 3 displays the tendencies for OFDM and UFMC in terms of BER depending on the SNR.

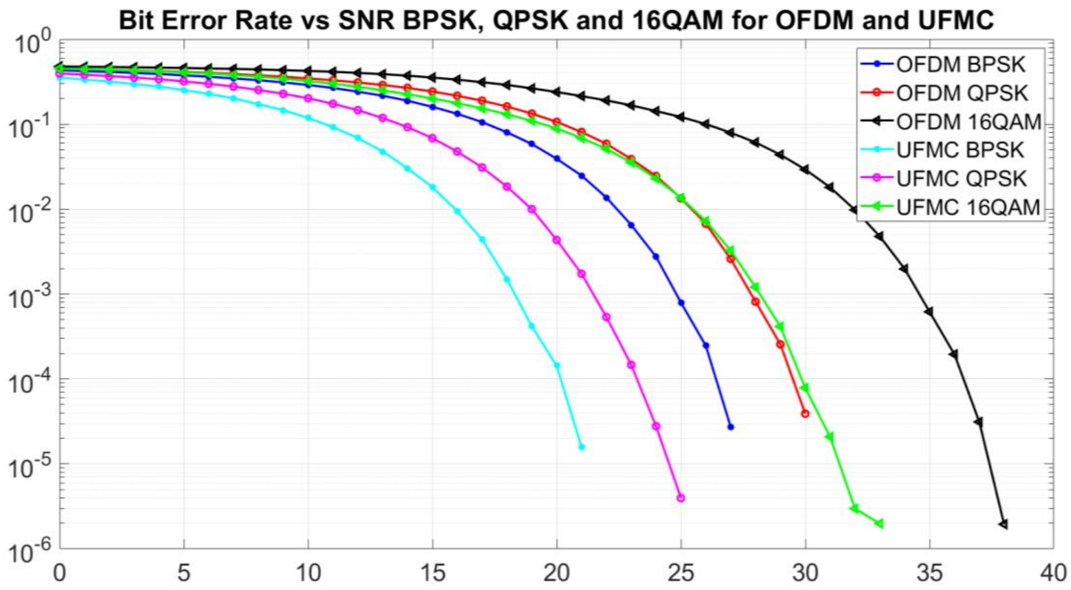

Figure 2: UFMC block diagram including juxtaposing technique

It can be observed that in general, the UFMC performs better than the OFDM. However, it must be taken into account that the dynamic range of the UFMC signal is greater than that for OFDM. To overcome this problem in either direction, the addition of an electronic bias can be done without changing the performance of the system. The difference between the QPSK and 16-QAM for both modulation techniques are the same. Thanks to the computation of the relative spectral efficiency gain, it highlights the gain of 16% when the UFMC is used instead of OFDM [5]. In terms of complexity, the filtering stage in UFMC constrains more computationally than OFDM. Further studies should be carried on to quantify it.

Conclusion

This work has presented the adaptations needed to use multicarrier modulation techniques for VLC. The major constraints are to have a real and positive signal. First, two techniques for rendering the real signal in OFDM were discussed in terms of spectral efficiency. Then, a comparison between OFDM and UFMC showed that the latter has better performance for the same simulation parameters.

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