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Performance evaluation of UFMC-based VLC systems using a modified SLM technique

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Abstract

Universal filtered multi-carrier (UFMC) is being studied as the favourable waveforms supporting the visible light communication broadcasting systems. However, the UFMC system faces a serious performance degradation on the transmitter side due to its high peak-to-average power ratio (PAPR). High PAPR of the signal is an analytical intention parameter for mobile networks, and it is necessary to minimize it as much as possible. This paper focuses on the PAPR reduction of the UFMC scheme. An efficient hybrid method of the PAPR reduction has been proposed and analysed through the Matlab™ simulation. The proposed hybrid scheme consists of a mixture of the selected-mapping method and the discrete Hartley transform precoding for a UFMC system (SLM-DHT-P-UFMC). The simulation results show that the proposed hybrid system has a better PAPR reduction performance compared to traditional SLM-UFMC and DHT-P-UFMC systems. Hence, SLM-DHT-P-UFMC is considered to be the suggested scheme in visible light communication broadcasting systems.

1. Introduction

Visible light communication (VLC) systems use light-emitting diodes (LEDs) to transmit data in the visible light spectrum. VLC is a preferable method for wireless data transmission in indoor environments, especially for low mobility and short-range applications [1]. A linear additive white gaussian noise (AWGN) channel is used for modelling VLC systems. An orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation scheme commonly used in 4G telecommunication systems such as long-term evolution (LTE). It suffers from some essential limitations including frequency leakage or high out-of-band due to using a rectangular pulse shape. The use of cyclic prefix (CP) leads to a failure in spectral efficiency and to the need for strict frequency and time synchronization to maintain the carrier orthogonally, assuring a low level of intercarrier interference. To overcome these drawbacks, over the past few years different alternative candidate schemes have been intensively studied, such as universal filtered multi-currier (UFMC), generalized frequency division multiplexing (GFDM), and filter bank multi-carrier (FBMC) [2]. Basic designs for successive VLC systems are under consideration, two more multi-carrier techniques. One of them is an FBMC technique. Compared to the OFDM modulation technique used in VLC systems, FBMC has fully isolated subcarriers by filtering, which decreases efficiency but increases robustness in synchronization errors. Another technique is UFMC and its performance analysis with OFDM under synchronization errors can be found in Ref. 3.

While OFDM can be thought of as a multi-carrier technique that divides a carrier into subcarriers, on the other hand, UFMC divides a carrier into sub-bands with each sub-band being further divided into subcarriers. This grouping of subcarriers reduces the filter length compared to FBMC. In OFDM, all carriers are filtered while UFMC

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applies filtering for each sub-band, thereby reducing the side-lobe levels of the carriers outside the sub-band. The UFMC technique provides better performance against synchronization errors which has been compared with the OFDM scheme [4]. Technique using a single carrier to transmit overall data is called a single carrier modulation. Battery power consumption and range extensions are main goals of giving preference to this method. To achieve high spectral efficiency in the single carrier method, complex equalizers are required. On the other hand, a multi-carrier modulation transforms a wideband single carrier into several orthogonal subcarriers. Visible light communication systems are required for the multi-carrier modulation to increase data transmission [5]. The main purpose of this paper is not only to introduce and compare the best multi-carrier waveforms candidate in general, but also to investigate a new hybrid technique consisting of a combination of the selected-mapping method and discrete Hartley transform precoding for the UFMC system (SLM-DHT-P-UFMC) for PAPR reduction in the UFMC system. The rest of the paper is structured as follows: section 2 reports a concise description of the OFDM system. A brief description of the UFMC system is presented in section 3. While PAPR is defined in section 4, section 5 shows a brief description of the proposed hybrid system. Then, in section 6, simulation results and discussion are introduced. Finally, a summary is reported in section 7.

2. OFDM system

Figure 1 shows the OFDM-based VLC system block diagram [6]. Firstly, a serial to parallel transformation is performed using a serial to parallel (S/P) conversion block in an OFDM system transmitter. Quadrature amplitude modulation (QAM) is performed on parallel data. Using an inverse fast Fourier (IFFT) processing which extracts a time domain signal from a frequency domain signal, the changed parallel QAM symbols are mapped to subcarriers. After IFFT, the parallel stream is converted into a serial stream by a parallel to serial (P/S) conversion block, then, a cyclic prefix (CP), being the copy of the symbol tail put at the beginning, is added providing a cyclic prefix block in order to eliminate the effect of inter-symbol interference (ISI). Finally, the LED is used for the visible light conversion. Optical channel is commonly used. At the receiver, a photodiode (PD) is used for bit conversion and the reversed operation to that of the transmitter of OFDM is performed.

OFDM consists of the total number of N_{sc} channels with the carrier frequencies $f_0, f_1, \ldots. f_{N_{sc}-1}$ in which each transmitted FDM signal can be described as:

$$X_K(t) = A_K(t)e^{j(\omega_K t+\emptyset_K(t))}\,, \tag{1}$$

where K is the channel index from 0 to N_{sc}–1, $A_K(t)$ is the amplitude of transmitted complex data at the K^{th} channel, ω_k is the angular frequency, and $\emptyset_K(t)$ is the phase at K^{th} channel. To simplify the equation, the pulse shape function is discarded. The combined FDM signal can be described as:

$$X(t) = \sum_{K=0}^{N_{SC}-1} A_K(t)e^{j(\omega_K t+\emptyset_K(t))}. \tag{2}$$

The amplitude and phase of subcarriers depend on the frequency of that particular subcarrier, therefore it can be rewritten as:

$$A_K(t) = A_K$$
$$\emptyset_K(t) = \emptyset_K.$$

This allows rewriting the complex continuous OFDM signal as:

$$X(t) = \sum_{K=0}^{N_{SC}-1} A_K e^{j(\omega_K t+\emptyset_K)}. \tag{3}$$

To evaluate the OFDM system performance, comparative simulation experiments are carried out using Matlab™ with system parameters seen in Table 1.

Table 1.
OFDM system parameters.

Parameter	Value
Bits per subcarrier	4
IFFT size	512
Number of subcarriers	384
Number of zeros	128
Cyclic prefix	6.25%
Raised cosine roll-off factor	0.2
Raised cosine filter order	32

3. UFMC system

For the next VLC system, UFMC is one of the new modulation techniques that are being considered. It overcomes some of disadvantages of modulation techniques

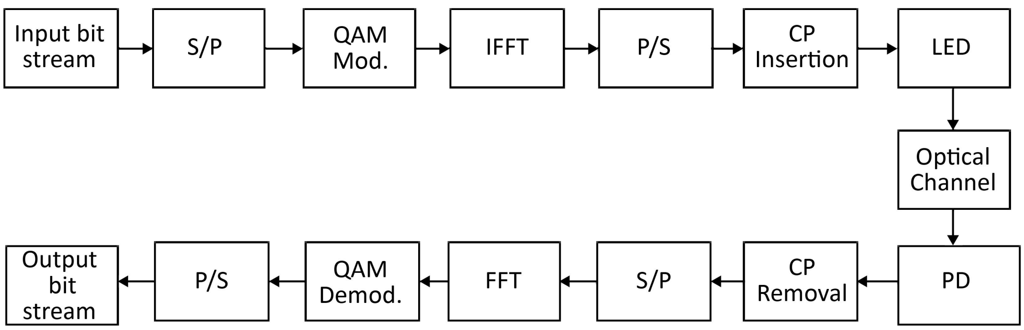

Fig. 1. FDM based VLC system block diagram [6].

which are used in traditional VLC systems. Instead of using a cyclic prefix in OFDM [7], sub-filtering is used. Figure 2 shows a UFMC-based VLC system block diagram and the data with a large number of input bits are converted into many sub-streams with a lower data rate. The full subcarriers band (N_sc) is split into sub-bands with a constant number of subcarriers for each sub-band. N IFFT points are performed for each sub-band, zeros are added for the unallocated carriers. Filtering processes are applied to each sub-band according to the filter length (L).

The responses of the various sub-bands are summed up at the 2N-FFT of the receiver by padding with zeros to recover data. To equalize the sub-band filtering, equalization per subcarrier is performed. Filtering results in a lower out-of-band (OOB) power emission than OFDM [8,9], therefore UFMC is considered in the next VLC system.

A key drawback of the UFMC is a large PAPR due to the in-phase addition in the IFFT. For a lower PAPR, a discrete Hartley transform (DHT) based on the UFMC precoding has been proposed in Ref. 10. New generalized precoding chirp for the UFMC system provides a 30% better PAPR [11].

To evaluate the performance of the UFMC-based VLC system, comparative simulation experiments using Matlab™ have been carried out with the system parameters displayed in Table 2.

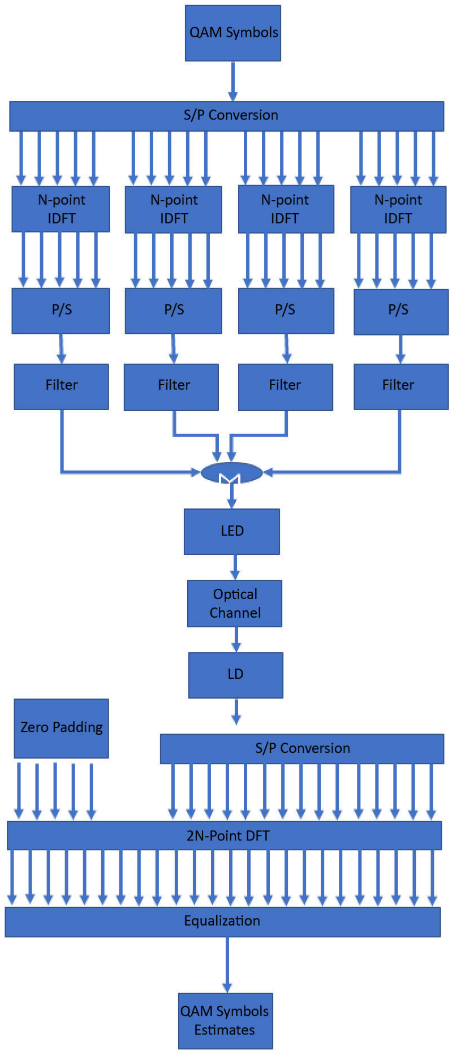

Fig. 2. UFMC-based VLC system block diagram [7].

Table 2.
UFMC system parameters.

Parameter	Value
Bits per subcarrier	4
IFFT size	512
Number of subcarriers	384
sub-band offset	64
sub-band size	64
Number of sub-bands	6
Dolph-Chebyshev filter length	10
Dolph-Chebyshev Side lobe attenuation	50

4. Peak-to-average power ratio (PAPR)

The ratio of the peak power to the average signal power is known as PAPR. To evaluate the performance of a PAPR reduction scheme, one of the most useful informative metrics is a complementary cumulative distribution function (CCDF):

$$PAPR = 10\log_{10}\frac{Peak\ power}{average\ power}\ . \quad (4)$$

Both OFDM and UFMC signals consist of many individually modulated subcarriers which, when summed coherently, give a very high amplitude resulting in a high PAPR. PAPR is directly proportional to the subcarrier numbers. On the transmitter side, due to the high PAPR, the quiescent point (Q-point) of the amplifier is forced to enter the non-linear region resulting in degradation of the amplification process [12]. Low PAPR reduces the complexity of digital-to-analogue and analogue-to-digital converters.

5. Proposed model

Various methods of PAPR reduction have been proposed in literature. Some of them are partial transmit sequence (PTS), clipping and filtering, tone reservation (TR), companding, tone injection (TI), precoding techniques, selected-mapping (SLM), or hybrid methods [13].

A comparative analysis of the combination of selected-mapping (SLM) and discrete Hartley transform (DHT) is presented in this paper.

5.1. Selected-mapping (SLM)

The selective mapping method is a promising PAPR reduction technique. Multiplying every subcarrier by the phase rotation factor is the basic concept of this scheme.

Phase rotation series is as follows:

$\theta = \theta_m (m = 0, 1, \ldots\ldots, K-1)$, expressed as:

$$\theta_m = e^{j\emptyset}, \emptyset \in [0, 2\pi]\ , \quad (5)$$

where K is the subcarrier number. After phase rotating, the mapping symbol X_m becomes:

$$X_m^R = X_m \times \theta_m = X_m\, g e^{j\emptyset}. \quad (6)$$

Then, X_m^R is the feed input symbol in the UFMC scheme and has experience in processing the rest. In the SLM method, the important key is the selection of the phase rotation factor θ_m which has a large impact on the PAPR performance [14].

5.2. *Discrete Hartly transform (DHT)*

Discrete Hartley transform (DHT) is a unitary change in which DHT transforms the real number sequences of $x_0, x_{1,}, x_{2,}, \dots x_{N-1}$ into a new sequence of real numbers of the same length $H_0, H_1, H_2, H_3, \dots H_{N-1}$. DHT can be defined as:

$$H_k = \sum_{n=0}^{N-1} x_n[\cos\left(\frac{2\pi nk}{N}\right) + \sin\left(\frac{2\pi nk}{N}\right)], \tag{7}$$

$$H_k = \sum_{n=0}^{N-1} x(n) \cdot \mathrm{cas}(\frac{2\pi nk}{N}), \tag{8}$$

where $k = 0, 1, \dots, N-1$ and $\mathrm{cas}\,\theta = \cos\theta + \sin\theta$. It is possible to define the DHT precoding matrix H of $N \times N$ size as:

$$H = \begin{bmatrix} h_{00} & \cdots\ \cdots & h_{0(N-1)} \\ \vdots & \ddots\ \ddots & \vdots \\ h_{(N-1)0} & \cdots\ \cdots & h_{(N-1)(N-1)} \end{bmatrix}, \tag{9}$$

where:

$$h_{m,n} = \mathrm{cas}\left(\frac{2\pi mn}{N}\right). \tag{10}$$

m and n are the integers from 0 to N–1. DHT matrix is invertible, thus, with the inverse of the DHT matrix, the original data can be obtained by a simple multiplication.

6. Simulation results and discussion

6.1. *Channel system*

The communication channel model is one of the most significant factors determining the efficiency of VLC systems. The communication channel would often be flat, especially when a strong line-of-sight (LoS) propagation path is presented. Visible light components are used for both lighting and wireless data communication. Transmitted signal is modulated by differentiating the optical power which is known as intensity modulation (IM). Signal detection is demodulated in the receiver by direct detection (DD). A linear additive white gaussian noise (AWGN) channel is used to model VLC systems. In the receiver, PD collects photons and then converts them into the electric current I_{PD}. The received optical power value is measured by:

$$P_r = \frac{I_{PD}}{R_{PD}}, \tag{11}$$

where R_{PD} is the PD responsivity.

The received power can be calculated using the optical wireless communication channel impulse response H_{OWC} by:

$$P_r = P_t H_{OWC} + N, \tag{12}$$

where P_t is the transmitted optical power and N is the AWGN.

Matlab™ simulations have been used with the above mentioned OFDM and UFMC parameters and additionally with LED power of 20 Watts, PD area A_{PD} of 10^{-4}cm^2, gain of optical filter and connectors of 1, and refractive index of a lens at a PD of 1.5. In this way the PAPR performance evaluation of the proposed VLC system using SLM-DHT-P-UFMC scheme can be investigated in detail.

Figure 3 shows the proposed VLC system using the SLM-DHT-P-UFMC scheme block diagram for a high PAPR reduction. In VLC using the SLM-DHT-P-UFMC

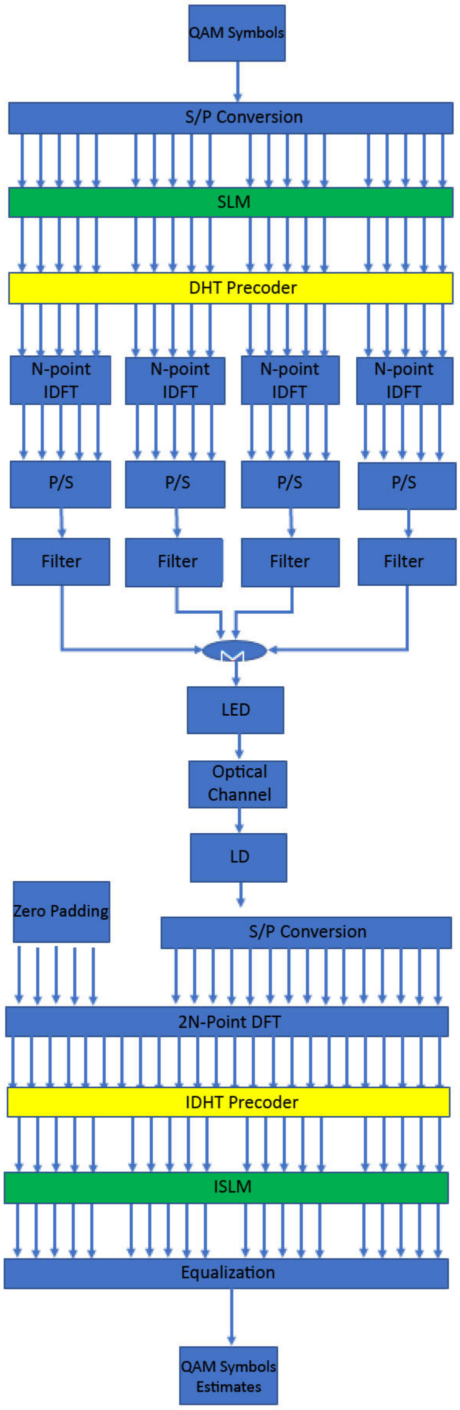

Fig. 3. Proposed SLM-DHT-P-UFMC scheme block diagram.

scheme, the main difference between the conventional VLC using UFMC, and the proposed model are two blocks, precoding SLM and DHT on the transmitter side and IDHT and ISLM on the receiver side. To reduce the high PAPR, a precoding matrix *H* of *N*×*N* dimension is applied to any SLM-QAM-based constellation symbols of size N.

Figure 4 shows CCDF *vs*. PAPR which means the PAPR probability is higher than the given PAPR0 value (Pr{PAPR>PAPR0}) for VLC-based UFMC, VLC-based DHT-P-UFMC, VLC-based SLM-UFMC, and VLC-based SLM-DHT-P-UFMC. It shows that for CCDF of 10^{-2}, the PAPR is of 10.8 dB, 10.6 dB, and 10.2 dB for UFMC, SLM-UFMC and DHT-P-UFMC, respectively. On the other hand, PAPR of the proposed hybrid model is of 9.9 dB. The proposed scheme can improve PAPR by 0.9 dB compared to the VLC-based UFMC scheme.

Figure 5 shows the power spectral density of OFDM, UFMC, and the proposed systems. It was observed that the spectra had a side lobe attenuation of −15 dB, −50 dB, and −55 dB, respectively. The result shows that the proposed scheme has the lower side lobe attenuation. This allows for a greater use of the spectrum allocated, leading to improved spectral efficiency. Thus, it is applicable to pack many frequency channels together without using guard bands.

Figure 6 shows BER performance *vs*. signal-to-noise ratio (SNR) of UFMC, DHT-P-UFMC, SLM-UFMC, and SLM-DHT-P-UFMC compared to OFDM. SNR needed for the BER of 10^{-3} is of 8.25 dB and 4.7 dB for OFDM and UFMC signals, respectively. Therefore, the UFMC technique improves SNR by 3.55 dB compared to the traditional VLC-based OFDM scheme.

The proposed scheme has a slight enhancement in BER performance compared to different VLC-based UMFC techniques.

7. Conclusions

This paper reviews the modulation waveform that is performed in a 4G OFDM communication system and demonstrates the VLC-based UFMC for next generations of cellular networks. The VLC-based UFMC technique faces a severe performance degradation due to PAPR on the transmitter side. Thus, a new proposed scheme composed of SLM-UFMC and DHT-precoding methods yields SLM-DHT-P-UFMC which is used for the PAPR reduction.

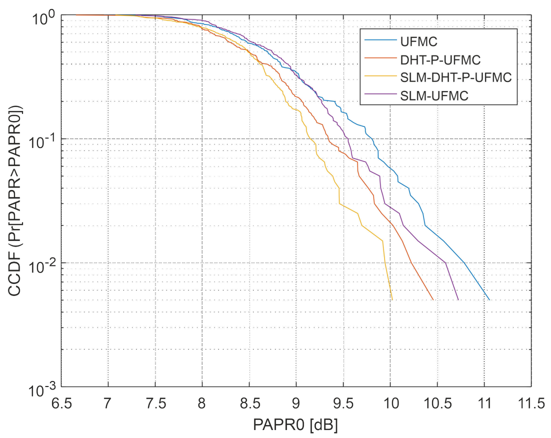

Fig. 4. CCDF *vs*. PAPR

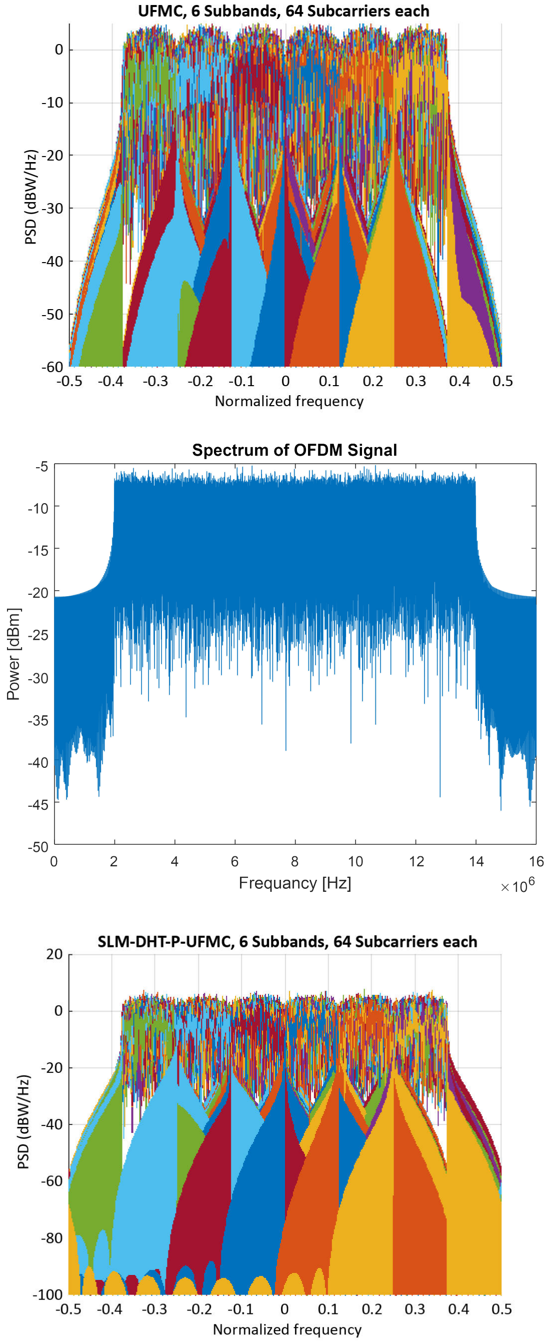

Fig. 5. Power spectral density performance.

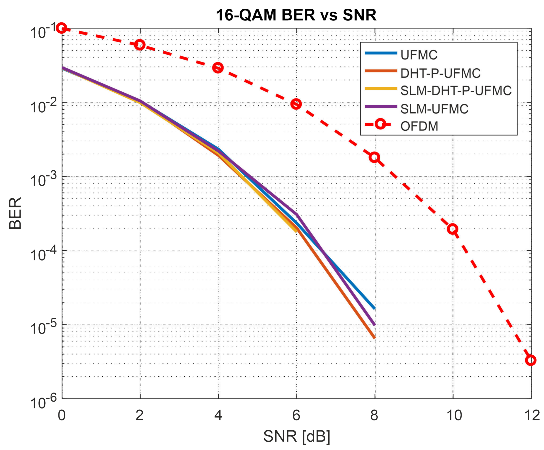

Fig. 6. BER *vs*. SNR.

In the suggested scheme, the SLM method followed by precoding into the constellation symbols reduces the autocorrelation relationship between constellation symbols which decreases the extra in-phase in IFFT input sequences. The in-phase addition in IFFT input sequences produces high peaks samples power, thus reducing the autocorrelation relationship in IFFT input sequences which leads to decreasing in-phase additions, hence PAPR is reduced.

Results show that the PAPR performance is improved by the proposed hybrid system compared to VLC-based SLM-UFMC and VLC-based DHT-UFMC. The VLC-based SLM-DHT-P-UFMC scheme is considered to be the suggested scheme in the next generation of the wireless VLC communication systems.

References

[1] Mohammed, N. A. & Elkarim, M. A. Exploring the effect of diffuse reflection on indoor localization systems based on RSSI-VLC. *Opt. Express* **23**, 20297–20313 (2015). https://doi.org/10.1364/OE.23.020297

[2] Gerzaguet, R. *et al*. The 5G candidate waveform race: a comparison of complexity and performance. *EURASIP J. Wirel. Commun. Netw*. **2017**, 13 (2017). https://doi.org/10.1186/s13638-016-0792-0

[3] Ambatali, C. D. M. & Marciano, J. J. S. Performance evaluation of the UFMC scheme under various transmission impairments. in *2016 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)* 24–28 (2017). https://doi.org/10.1109/COMNETSAT.2016.7907410

[4] Vakilian, V., Wild, T., Schaich, F., Ten Brink, S. & Frigon, J. F. Universal-filtered multi-carrier technique for wireless systems beyond LTE. in *2013 IEEE Globecom Workshops (GC Wkshps)* 223–228 (2013). https://doi.org/10.1109/GLOCOMW.2013.6824990

[5] Naga Rani, P. & Santhi Rani, C. H. UFMC: The 5G modulation technique. in *2016 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)* (2016). https://doi.org/10.1109/ICCIC.2016.7919714

[6] Jebbar, H., El Hassani, S. & El Abbassi, A. Performance study of 5G multicarrier waveforms. in *2017 International Conference on Wireless Networks and Mobile Communications (WINCOM)* (2017). https://doi.org/10.1109/WINCOM.2017.8238183

[7] 5G Waveform Candidates: Rohde & Schwarz White Paper - GSA. https://gsacom.com/paper/5g-waveform-candidates-rohde-schwarz-white-paper/

[8] Wild, T., Schaich, F. & Chen, Y. 5G air interface design based on universal filtered (UF-)OFDM. in *2014 19th International Conference on Digital Signal Processing*, 699–704 (2014). https://doi.org/10.1109/ICDSP.2014.6900754

[9] Schaich, F., Wild, T. & Chen, Y. Waveform contenders for 5G - Suitability for short packet and low latency transmissions. in *2014 IEEE 79th Vehicular Technology Conference (VTC Spring)* (2014). https://doi.org/10.1109/VTCSpring.2014.7023145

[10] Baig, I. *et al*. A low PAPR DHT precoding based UFMC scheme for 5G communication systems. in *2019 6th International Conference on Control, Decision and Information Technologies (CoDIT)* 425−428 (2019). https://doi.org/10.1109/CoDIT.2019.8820502

[11] Baig, I. *et al*. A Low PAPR universal filtered multi-carrier system for 5G machine type communications. in *2019 Wireless Days (WD)* 1–4 (2019). https://doi.org/10.1109/WD.2019.8734188

[12] Misra, J. & Mandal, R. Comparative analysis of PAPR reduction techniques in OFDM using precoding techniques. *Int. J. Sci. Res. Dev*. **3**, 1041–1043 (2015).

[13] Sandoval, F., Poitau, G. & Gagnon, F. Hybrid peak-to-average power ratio reduction techniques: review and performance comparison. *IEEE Access* **5**, 27145–27161 (2017). https://doi.org/10.1109/ACCESS.2017.2775859

[14] Zhang, Y., Liu, K. & Liu, Y. A Novel PAPR reduction algorithm based on SLM technique in UFMC systems. in *2018 IEEE/CIC International Conference on Communications in China (ICCC Workshops)* 178–183 (2018). https://doi.org/10.1109/ICCChinaW.2018.8674491