Usage of Channel Coding Techniques for Peak-to-Average Power Ratio Reduction in Visible Light Communications Systems

P.L.D.N.M. de Silva, S.G. Edirisinghe, R. Weerasuriya

Abstract—High Peak-to-Average Power Ratio (PAPR) is a concern of Orthogonal Frequency Division Multiplexing (OFDM) based Visible Light Communication (VLC) systems. Discrete Fourier Transform spread (DFT-s) OFDM is an alternative single carrier modulation scheme which would address this concern. Employing channel coding techniques is another mechanism to reduce the PAPR. In this study, the improvement which can be harnessed by hybridizing these two techniques for VLC system is being studied. Within the study, efficient techniques such as Hamming coding and Convolutional coding have been studied. Thus, we present the impact of the hybrid of DFT-s OFDM and Channel coding (Hamming coding and Convolutional coding) on PAPR in VLC systems, using MATLAB simulations.

Keywords—Convolutional Coding, Discrete Fourier Transform spread Orthogonal Frequency Division Multiplexing (DFT-s OFDM), Hamming Coding, Peak-to-Average Power Ratio (PAPR), Visible Light Communications (VLC).

I. Introduction

VISIBLE light communications is one of the emerging wireless communications technologies at present. It is being considered as an alternative to the Radio Frequency (RF) communication which has the drawbacks of limited spectrum and high cost for the spectrum. DFT-s OFDM is a single carrier modulation scheme which is able to reach higher data rates in VLC systems. When it comes to OFDM-based systems, high PAPR is one of the drawbacks, as it would lead the system to operate in a non-linear range of the power amplifiers in the system [1]. DFT-s OFDM is capable of reducing the PAPR compared to other OFDM techniques [2]. However, there are ongoing studies to investigate techniques to reduce PAPR in VLC systems further.

There are different techniques which have been implemented to reduce PAPR in RF wireless communications. Those techniques can be categorized as Coding, Multiple Signaling and Probabilistic (MSP), Signal Distortion (SD) and Hybrid. Coding techniques can be further categorized as linear block coding, convolutional coding and concatenate coding with specific techniques such as Hamming coding, Traditional convolutional coding with Viterbi decoding and Reed-Solomon coding with Viterbi decoding respectively. MSP category includes techniques such as Partial Transmit Sequence (PTS), Interleaving, Pre-distortion, etc. DFT-s which is discussed above, is one of the pre-distortion techniques. SD category includes techniques such as Clipping and filtering, Peak windowing, etc. Hybrid category includes a combination of two or more techniques of the previous categories [1].

Some of the above mentioned techniques such as Turbo Codes under Coding category, PTS, DFT-s OFDM under MSP category and Clipping under SD category have been already researched in the VLC domain [3], [4]. In this research work, it is expected to carry out a simulation-based study on the impact of combining DFT-s OFDM with Coding techniques, specifically Hamming coding and Traditional convolutional coding for a VLC system. By employing channel coding, it is possible to reduce PAPR while increasing the reliability of the data transmission, which is another value addition to the VLC system.

P.L.D.N.M. de Silva is with the Department of Electronics and Telecommunications Engineering, University of Moratuwa, Sri Lanka and with the School of Engineering, Sri Lanka Technological Campus, Sri Lanka (e-mail: desilvapldnm.21@uom.lk).

S.G. Edirisinghe is with the Department of Electrical and Electronic Engineering, Kotelawala Defence University, Sri Lanka (e-mail: sumudu1975@googlemail.com).

R. Weerasuriya is with the Department of Electronics and Telecommunications Engineering, University of Moratuwa, Sri Lanka (e-mail: ruwanu@uom.lk).

II. System Description

A. VLC System Architecture

A VLC system consists of an Access Point (AP), a wireless channel and a user device. In case the system is bi-directional, both the AP and the user will have an LED as the transmitting component and a Photodetector as the receiving component. The processing unit at the transmitter modulates the signal and sends the modulated signal through a driver circuit to the LED lamp. The signals are transmitted by variations in the illumination of the LED, which is known as Intensity Modulation (IM). The optical signals travel through the free space. At the receiver side, the photodiode captures the intensity of the signal through Direct Detection (DD) and recovers the original signal with appropriate signal processing [2], [3], [4].

In this research, it is considered that the input data bits are first channel coded using either Hamming coding or Traditional convolutional coding. Then, the output bit stream is mapped to symbols using Quadrature Amplitude Modulation (QAM) mapping. Resulting symbols are then modulated through the DFT-s OFDM modulator. PAPR at the modulator output is considered for the analysis.

B. Channel Coding Techniques

1) Hamming Coding: Hamming coding is categorized under the linear block codes. This coding scheme processes the input bit stream by dividing the stream into fixed-length blocks for which a fixed-length code word is generated using a generator matrix. The receiver detects errors in the incoming code word based on the syndrome and corrects the errors according to the identified error patterns. Thus, it is employed in communication systems as a forward error correcting technique, which assists in detecting and correcting errors at the receiver side [5], [6]. However, in this research, it is expected to prove that in addition to the error correction capability, this coding scheme is capable of reducing the PAPR in VLC systems.

2) Traditional Convolutional Coding: Traditional convolutional coding is also a forward error correction technique which generates a code word not only based on the current input bit, but also considering one or more previous input bits as well. It does not treat the input bit stream as blocks, but gives a single output code word for the input bit stream at once. Decoding is done using the Viterbi algorithm which estimates the transmitted bit sequence based on the likelihood function. This is also widely used in communications systems as a forward error correcting technique [5], [6]. This study demonstrates its capability in reducing the PAPR in VLC systems.

C. DFT-s OFDM Technique

DFT-s OFDM is a single carrier modulation technique which has provided low PAPR compared to other OFDM-based modulation schemes in VLC systems. Incoming channel coded bit streams are mapped to a QAM constellation followed by the DFT. The output of the DFT is further processed by adding zeros, either as localized or interleaved method. As VLC systems operate with intensity modulation and direct detection (IM/DD), the baseband signal modulates the intensity of the light. Thus, the OFDM baseband signal should be a real signal. Nevertheless, the processed signal at this stage is a complex signal, Hermitian symmetry is applied to the zero-added DFT output to obtain a real signal. This is then subjected to the OFDM operation, which is the IFFT. In order to minimize the inter-symbol interference (ISI), a cyclic prefix is added to the OFDM symbol which results in the final OFDM frame [2], [3], [4].

III. Simulation Details

A. Parameters

The simulations have been carried out for the PAPR parameter, which is defined as shown in (1):

$$PAPR = \frac{max\{|s(t)^2|\}}{E\{|s(t)^2|\}} \tag{1}$$

The complementary cumulative density function (CCDF) has been used to analyze the performance of the PAPR for different scenarios considered. The CCDF will give the insight of the probability that the PAPR of the OFDM symbols will be greater than a particular considered value. In order to have more reliable PAPR plots, carrying out the simulations for a large number of iterations would be optimum. The number of iterations which has been considered for the presented simulations is 10,000.

B. Methodology

Simulation in this study has been done using the MATLAB software. First, the PAPR performance of DFT-s OFDM is studied for localized and interleaved methods using 4-QAM and 16-QAM mapping, without any channel coding technique. 4-point DFT and 16-point IFFT have been considered at this stage. Then, the study was developed in to Hamming coding, where the (7,4) and (127,120) coding schemes are applied prior to the DFT-s OFDM stage. Next, the Traditional convolutional coding is applied prior to the DFT-s OFDM stage using the (2,1,2) coder with different outputs as well as the same outputs. Both the 4-QAM and 16-QAM have been considered for both the channel coding schemes as well. As the number of bits are high for these scenarios, 64-point DFT and 256-point IFFT have been considered.

IV. Results and Discussion

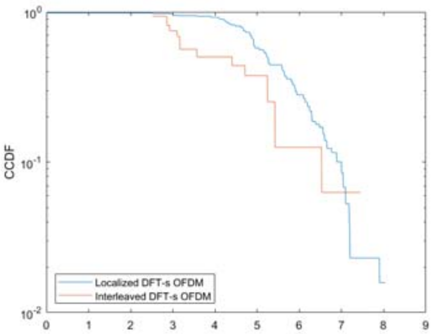
The generation of PAPR plots for DFT-s OFDM without channel coding, with Hamming coding and with Traditional convolutional coding has been generated and the results along with the discussion is presented in this section.

A. Analysis of Results

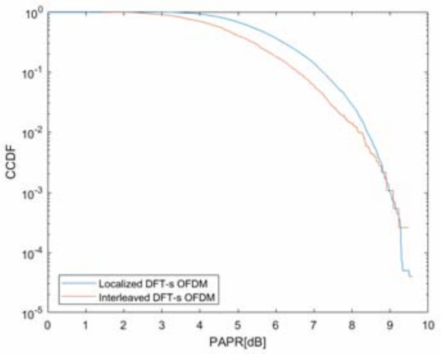
According to the plots obtained for DFT-s OFDM without channel coding, it can be seen that the interleaved method provides the same or a better PAPR performance compared to localized method. Further, it can be seen that PAPR performance degrades for higher modulation schemes (16-QAM), compared to lower order modulation schemes (4-QAM). These observations can be seen in Fig. 1. The PAPR plot for 4-QAM shows a step-wise graph, specially in the interleaved method. The reason for this observation is that for the 256 different symbol combinations which may appear as the input to the 4-point DFT, only 12 distinct PAPR values will exist for the interleaved method. However, for the same 256 symbol combinations, there will be 71 distinct PAPR values for the localized method leading to more number of steps in the PAPR plot.

The next set of simulations were done using the Hamming coding technique. First, the analysis was done for (7,4) Hamming codes and it was observed that the PAPR performance with (7,4) Hamming coding was worse than that without channel coding. This can be observed in Fig. 2. Thus, the simulations were redone for (127,120) Hamming code. As per the simulation plots received, it was able to identify that the PAPR performance has improved with this higher order coding scheme. These observations can be seen in Fig. 3.

As the final set of simulations, the traditional convolutional coding was tested considering a (2,1,2) encoder with 4-QAM mapping. From the simulation results, it was possible to identify that the PAPR in the system is further improved when the two outputs (impulse responses) are not identical. However, when the two outputs are identical, it can be seen that the performance of the convolutional coding degrades even than when no channel coding was used. Fig. 4 presents these observations among the three scenarios for both localized and interleaved methods. Further, the convolutional coding was changed to (2,1,7) encoder with 4-QAM mapping to see the effect of the change in constraint length on the PAPR. Fig. 4 represents the results related to this configuration and by comparing the two results, it can be concluded that no significant impact is made to PAPR with the change of the constraint length in convolutional coding.



(a) 4-QAM



(b) 16-QAM

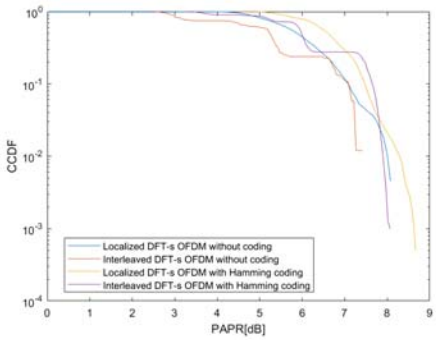
Fig. 1 PAPR for DFT-s OFDM without channel coding

B. Summary of Results

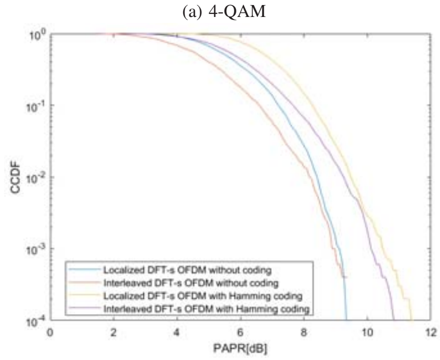
Table I is a comparison of the PAPR values obtained by the considered techniques for a CCDF value of 0.01. This clearly depicts that the PAPR has been improved by implementing Channel coding techniques.

TABLE I
COMPARISON OF PAPR FOR A CCDF OF 0.01

Technique	PAPR(dB)
Localized without Channel coding	9.879
Interleaved without Channel coding	9.643
Localized with (127,120) Hamming Coding	9.35
Interleaved with (127,120) Hamming Coding	9.335
Localized with (2,1,7) Convolutional Coding	9.271
Interleaved with (2,1,7) Convolutional Coding	9.12

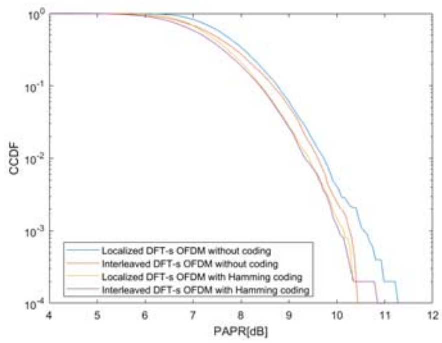


(a) 4-QAM

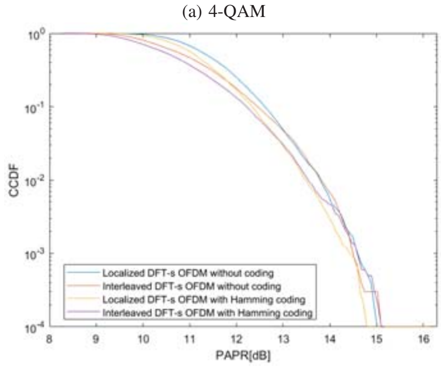


(b) 16-QAM

Fig. 2 PAPR Comparison without channel coding and with (7,4) Hamming coding

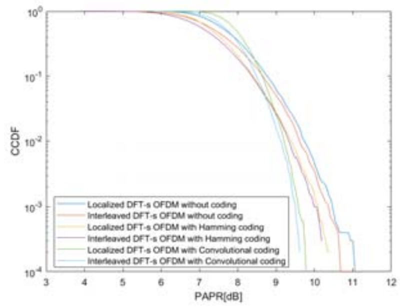


(a) 4-QAM

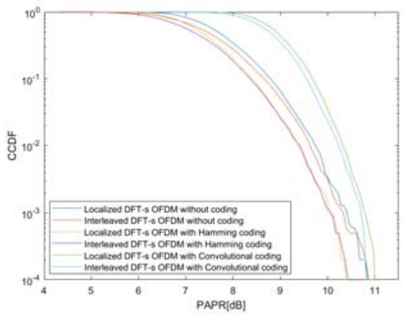


(b) 16-QAM

Fig. 3 PAPR Comparison without channel coding and with (127,120) Hamming coding

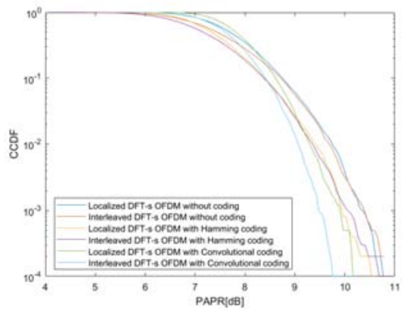


(a) Different outputs for Convolutional coding

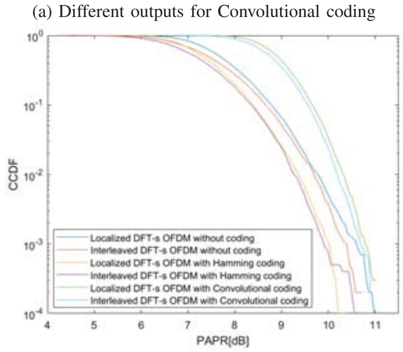


(b) Same outputs for Convolutional coding

Fig. 4 PAPR Comparison without channel coding, with (127,120) Hamming coding and (2,1,2) Convolutional coding for 4-QAM



(a) Different outputs for Convolutional coding



(b) Same outputs for Convolutional coding

Fig. 5 PAPR Comparison without channel coding, with (127,120) Hamming coding and (2,1,7) Convolutional coding for 4-QAM

V. Conclusion

This research work has focused on analyzing the impact on PAPR in DFT-s OFDM-based VLC systems, with the use of Channel coding techniques. Initially, it has been identified that when the QAM mapping order is increased, the PAPR performance becomes worse. During the research, simulations related to Hamming coding and Convolutional coding have been considered to quantify the impact on PAPR. The simulation-based study has shown that Channel coding techniques are capable of reducing the PAPR, specifically (2,1,2) and (2,1,7) Convolutional coding being better than (127,120) Hamming coding. For a CCDF value of 0.01, (2,1,7) Convolutional coding has shown a reduction of approximately 0.5 dB and 0.6 dB in PAPR and (127,120) Hamming coding a reduction of approximately 0.3 dB and 0.5 dB, compared to the scenario where no channel coding is used for interleaved and localized methods respectively. So, it can be concluded that the considered channel coding techniques improve the PAPR performance, while the improvement in localized DFT-s OFDM seems to be slightly higher than that in interleaved DFT-s OFDM.

Another observation made during the work was that (7,4) Hamming coding worsened the PAPR, whereas (127,120) Hamming coding improved the system performance. Simultaneously, different outputs (impulse responses) in convolutional coding improved the PAPR performance, whereas similar outputs worsened the situation. Thus, it can be concluded that channel coding can reduce the PAPR issue in DFT-s OFDM-based VLC systems with careful selection of parameters related to the coding scheme. However, the effective data rate in (2,1,2) and (2,1,7) convolutional coding would get reduced, as the number of parity bits added during the channel coding is high compared to (127,120) Hamming coding. Ultimately, the selection of the Channel coding technique for a particular VLC system should be done based on the data rate, PAPR and bit error rate requirements of the relevant VLC application.

References

[1] F. Sandoval, G. Poitau, and F. Gagnon, "Hybrid peak-to-average power ratio reduction techniques: Review and performance comparison," *IEEE Access*, vol. 5, pp. 27 145–27 161, 2017.

[2] C. Wu, H. Zhang, and W. Xu, "On visible light communication using led array with dft-spread ofdm," in *2014 IEEE International Conference on Communications (ICC)*. IEEE, 2014, pp. 3325–3330.

[3] Z. Fulai, L. Luokun, and Y. Jinjin, "Dft-spread combined with pts method to reduce the papr in vlc-ofdm system," in *2014 IEEE 5th International Conference on Software Engineering and Service Science*. IEEE, 2014, pp. 629–632.

[4] Y. Cheng, J. Zhang, J. Zhang, M. Xiao, R. Deng, and L. Chen, "Dft-spread combined with clipping method to reduce the papr in vlc-ofdm system," in *2017 4th International Conference on Information Science and Control Engineering (ICISCE)*. IEEE, 2017, pp. 1462–1466.

[5] K. D. Rao, *Channel coding techniques for wireless communications*. Springer, 2015.

[6] J. G. Proakis and M. Salehi, *Digital communications*. McGraw-hill New York, 2001, vol. 4.

P.L.D.N.M. de Silva received her B.Sc. (Honours) degree with a First Class from the Department of Electronics and Telecommunications Engineering, University of Moratuwa, Sri Lanka in 2007. She is currently pursuing her Ph.D. degree with the same, Department of Electronics and Telecommunications Engineering at University of Moratuwa, Sri Lanka. She is also a lecturer in Electronics and Telecommunications Engineering under the School of Engineering at Sri Lanka Technological Campus, Sri Lanka. She has a 12 years experience in the Sri Lankan telecommunications industry in the Access Network Planning and Optimization domain. Her research interests include Visible Light Communication (VLC), Light Fidelity (Li-Fi) and Wireless Communications.

S.G. Edirisinghe obtained a 1st class honors degree in Electronic Systems Engineering from University of Essex in 1997and in 2001 was awarded a PhD in Optical communications by University of Essex for his research work on high-speed dispersion tolerant transmission systems. Over the next 20 years he has been working as an R&D and a design Engineer for several telecommunication equipment manufactures in Europe and USA, designing, developing products and testing transmission equipment for fiber optic communication systems. He is well versed in handling and designing transceivers with high-speed optical components such as LASERs and photodiodes. He hold a US patent and has several publications in the area of expertise. He is an international consultant in submarine fibre optic cables and a visiting lecturer in optical communication at Kotelawala Defense University, Sri Lanka.

R. Weerasuriya received a B.Sc.Eng. degree from the University of Moratuwa, Moratuwa, Sri Lanka, in 2002, and the M.Sc. degree from the University of Nottingham, Nottingham, U.K., in 2007, and 2011 was awarded a Ph.D. in Physics specializing in Photonic Systems by University College Cork (Tyndall National Institute), Ireland for his research work on Data retiming for multiwavelength regeneration. He was with Dialog Telekom Ltd., Sri Lanka, as a specialist where he was engaged in the field operations of the terrestrial microwave, satellite transmission, and network monitoring systems. Currently, he is a Professor in the Department of Electronics and Telecommunications Engineering, University of Moratuwa. His research interests include the study of long-haul optical transmission systems, fiber nonlinearities and their applications, and optical regeneration methods in high-speed optical networks. He is the author or co-author of more than 12 journal papers as well as 25 conference papers and holds a patent published in the field of photonics. Prof. Weerasuriya is a senior member of the Institute of Electrical and Electronic Engineers (IEEE) and Optical Society of America (OSA), USA. He was a reviewer for the many engineering conferences and Journals.