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UNIVERSITY OF SURREY

Power-efficient waveforms for visible light communication

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Radio Access Network Techniques for 6G
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Outline

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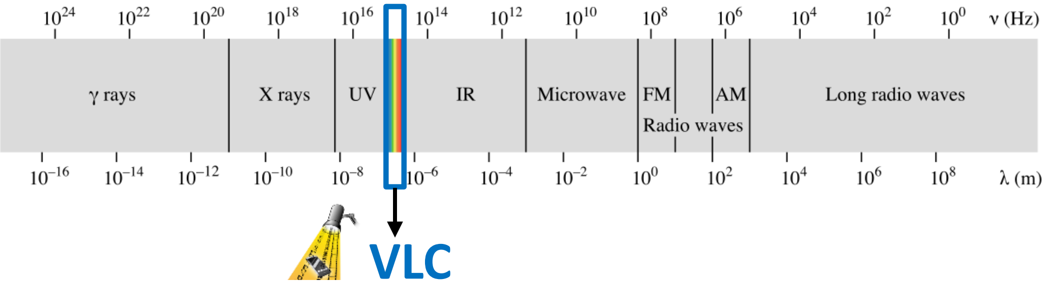
- Background, Motivation & Objectives
- Single-carrier waveform design
- Multi-carrier waveform design
- Summary & Future work

Background

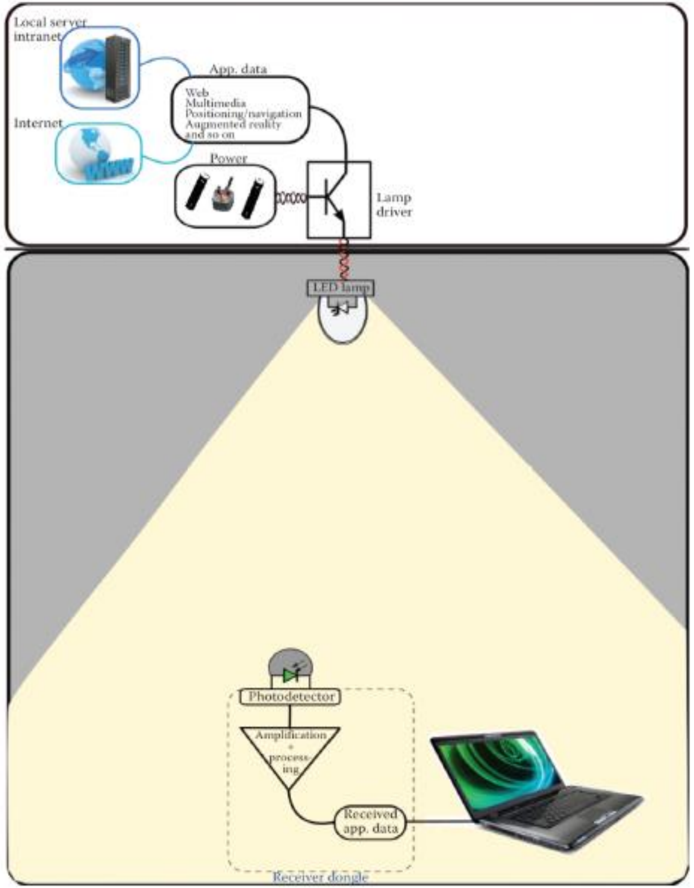


- Visible Light communication (**VLC**): **short-range optical wireless communication** using the visible light spectrum from 380 to 750 nm (~400 to 790 THz).

- Main applications: **indoor**, outdoor hotspot, **RF non-desirable environment** (e.g. hospital, school, plane), under water communication

Background (cont’d)

- VLC technology mainly relies on **intensity modulation** (IM) and **direct detection** (DD) as transceiving techniques
  - ? only the **envelope** (**amplitude**) of the signal is transmitted/deteted
  - ? The ~~phase~~ cannot be recovered ? traditional RF
  - ? The **envelope** is non-negative (a.k.a **unipolar**)

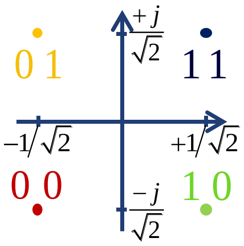


Motivation/ Objectives

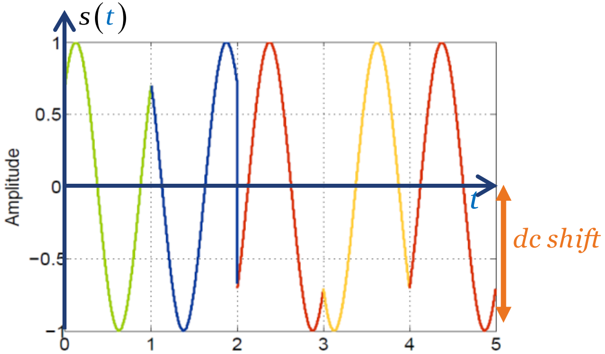
- Design **practical** power efficient (**PE**) and spectral efficient (**SE**) transmission / modulation scheme for VLC:
  - Efficiently **adapt RF transmission** / modulation scheme, e.g. quadrature amplitude modulation (QAM) and orthogonal frequency division multiplexing (OFDM) **to VLC**
  - Take **practical aspects** into account, e.g. implementation complexity, peak to average power ratio (PAPR), inter-channel interference (ICI)

Adapting QAM to VLC

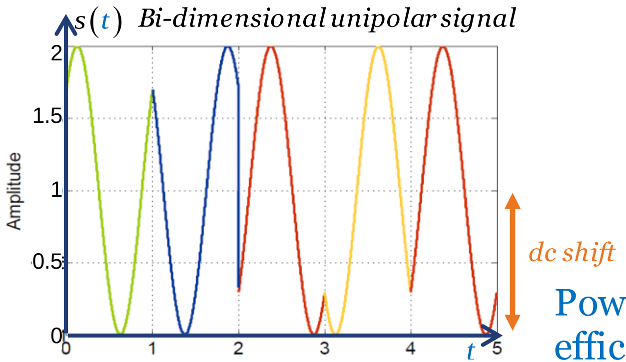
- Design practical power efficient transmission / modulation scheme for VLC: $x = [1-j;\ 1+j;\ -1-j;\ -1+j;\ -1-j]/\sqrt{2}$



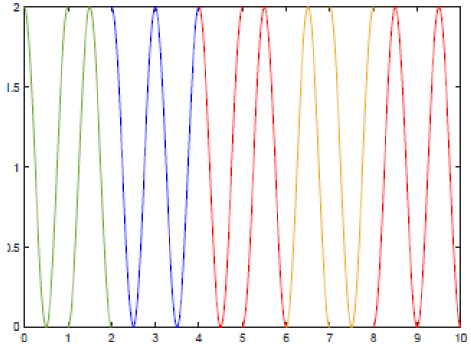
Normalised 4-QAM constellation



Bi-dimensional bipolar signal



Power efficiency

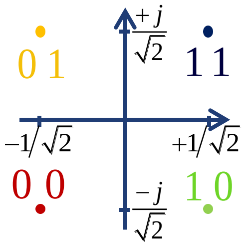


Spectral efficiency

unidimensional unipolar signal

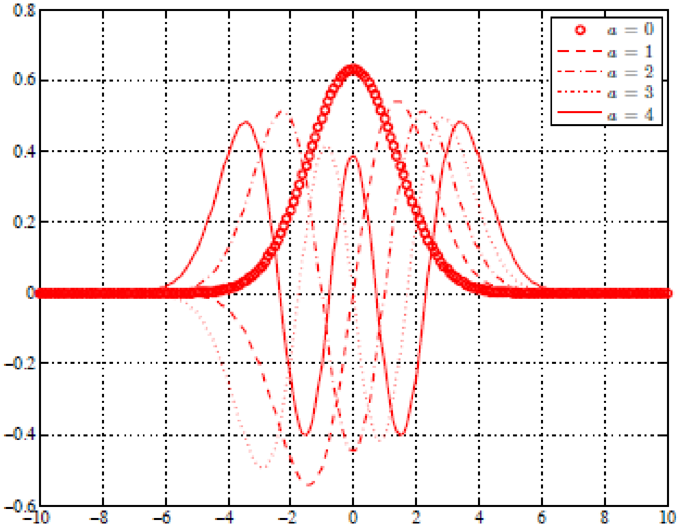
Adapting QAM to VLC: orthogonal waveforms

- QAM ⍰ **2-dimensional modulation**
  - Cosine and sine forms a **2D orthonormal basis**
  - Cosine and sine have the **same shape**; **orthogonality** created through **phase**



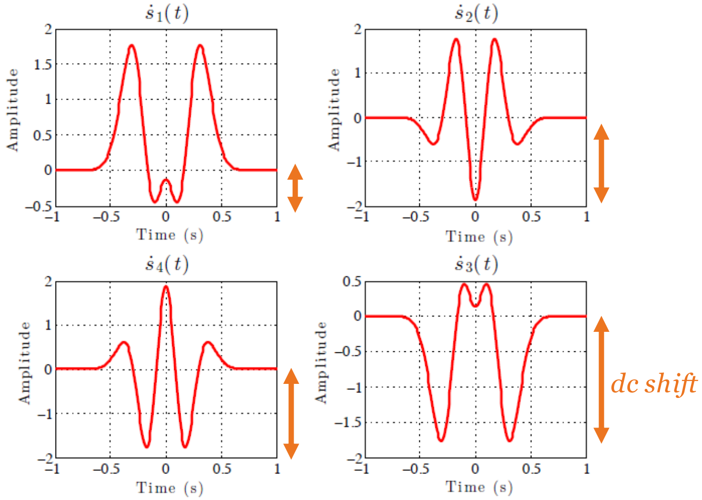
- What if we could create **orthogonality** through **shape** instead of phase?
  - Yes, **we can**…

Modified Hermite waveforms (MHWs) time response



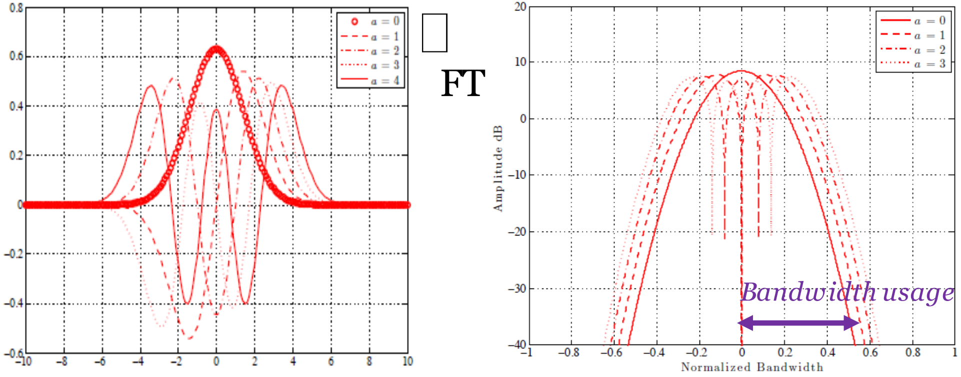
Mimicking QAM with MHW I

- How to **chose** the waveforms to design a **power** and **spectral efficient** modulation?
  - Power efficiency → minimum **Dc shift**
  - Spectral efficiency → minimum **bandwidth usage**



Example of 4 state modulation with MHWs

MHW time and frequency response



Mimicking QAM with MHW II

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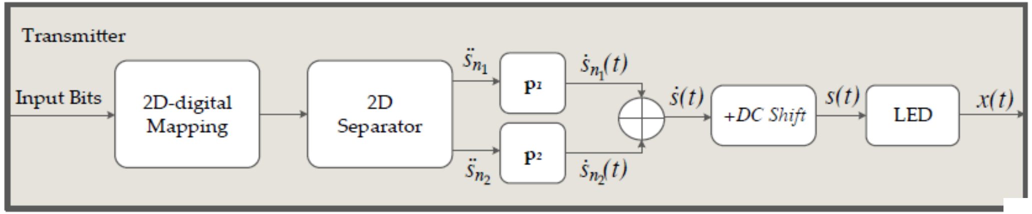
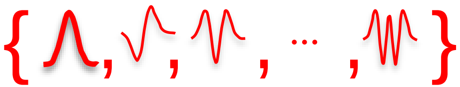
- <u>Idea 1:</u> use **two** orthogonal waveforms out of a set of MHWs
  - one for “real” part (p_1), one for “imaginary” part (p_2)

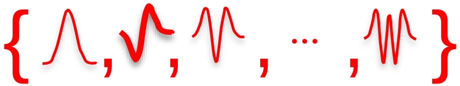


  - E.g. 4 state modulation

{-0.7, 0.7} x 

Set of amplitudes — Set of waveforms (“real”)

\+

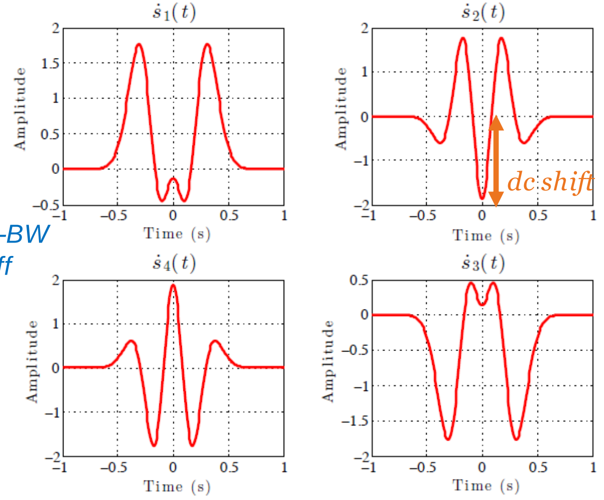
{-0.7, 0.7} x 

Set of amplitudes — Set of waveforms (“imaginary”)

=

Best dc offset-BW usage trade-off

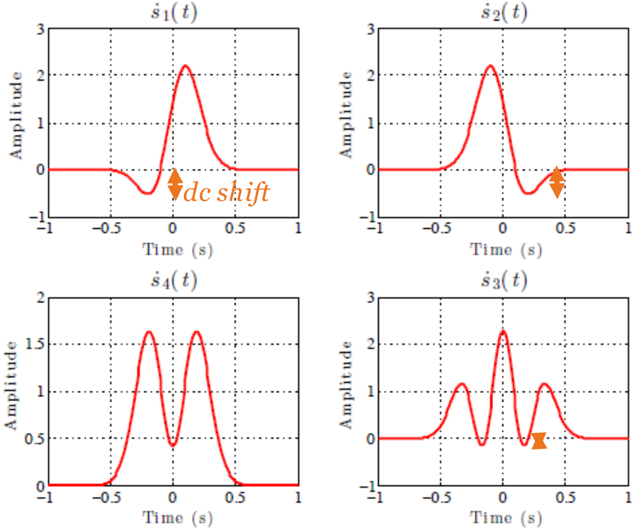
Optimal 4-state modulation with ***2*** *MHWs*



Mimicking QAM with MHW III

- <u>Idea 2:</u> find the **best** combination of waveforms to **minimise** the **dc offset**
  - **More than** one waveform for encoding the “real” part and/or “imaginary” part

*Optimal 4-state modulation with **4** MHWs*



\+ □ **dc shift** □□ **PE**

\- Waveforms with larger bandwidth are used □ □ **SE**

\- □ **complexity** of decoding

Mimicking QAM with MHW IV

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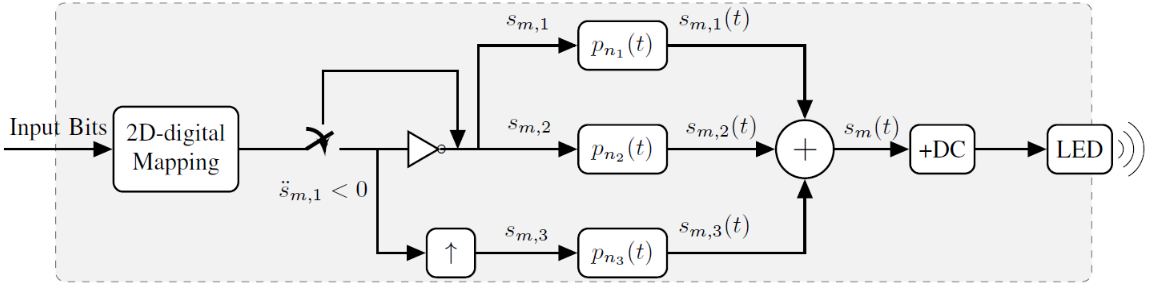
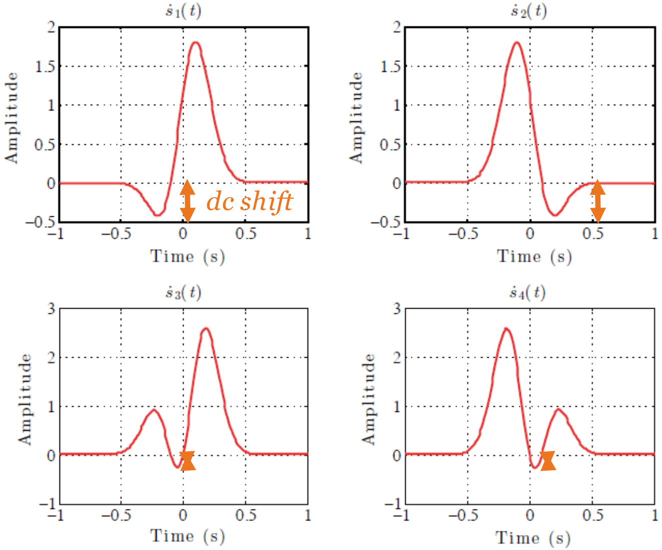
- <u>Idea 3:</u> use **dedicated** waveforms for orthogonality and polarity
  - **Two** MHWs to create **orthogonality** (“real” and “imaginary”) and **one** for **polarity** (reduce **dc shift**)



*Optimal 4-state modulation with **3** MHWs*

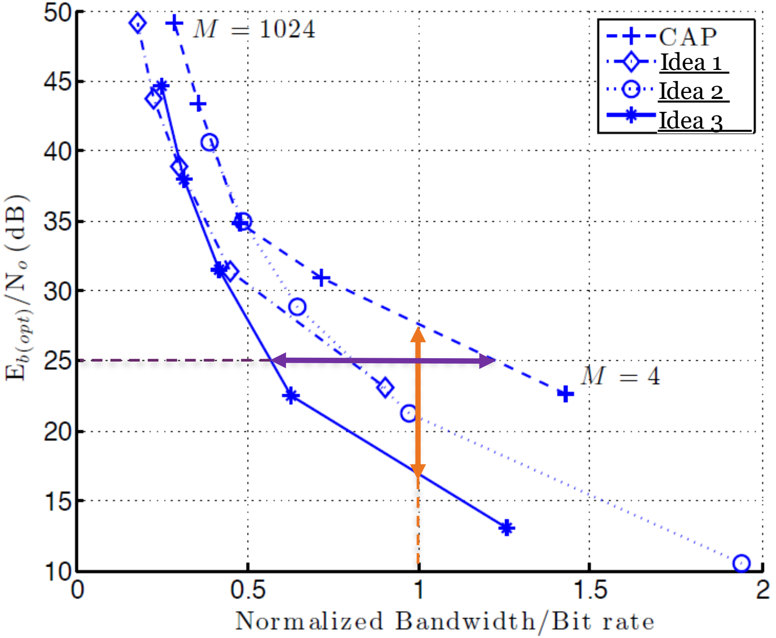


+ □ **dc shift** □□ **PE** (vs. <u>idea 1</u>)

+ □ **BW usage** □□ **SE** (vs. <u>idea 2</u>)

- □ **complexity** of decoding (<u>vs. idea 1</u>)

Performance Analysis



Eb/N_0 vs. normalised bandwidth/bit rate comparison of CAP, idea 1, idea 2 and idea 3 for a BER of 10^{-4} and normalized optical power when M = 4; 16; 64; 256 and 1024.

- *Benchmark:* carrier-less amplitude and phase (CAP) modulation (use two **root raised cosine filter** to mimic “real” and “imaginary” part of QAM)
- All our schemes provides a **better PE** (? **dc shift**) and/or **better SE**(? **bandwidth usage**) than CAP
  - Idea 3: **10 dB more PE** than CAP for a normalised BW of 1
  - Idea 3: more than **2 times better SE** than CAP for an E_b/N_0 of 25 dB
- Idea 3 provides **the best PE-SE trade-off**, but at the expense of **transceiver complexity**

Adapting OFDM to VLC: SoTA

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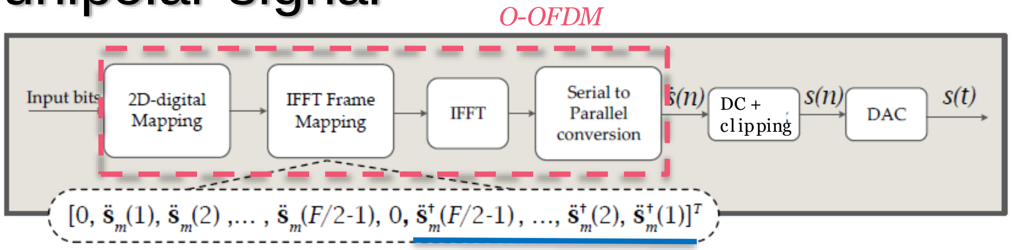
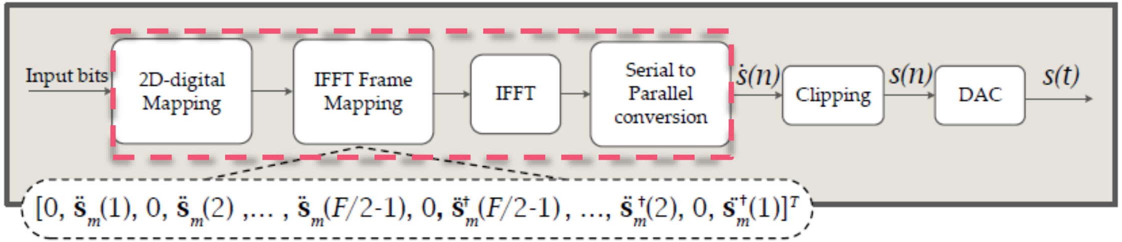
- Direct current Optical (DCO)-OFDM: use **half** of the subcarriers (a.k.a **Hermitian symmetry**) plus DC & clipping to generate a unipolar signal



□ ½ **SE** of OFDM + □ **PE**

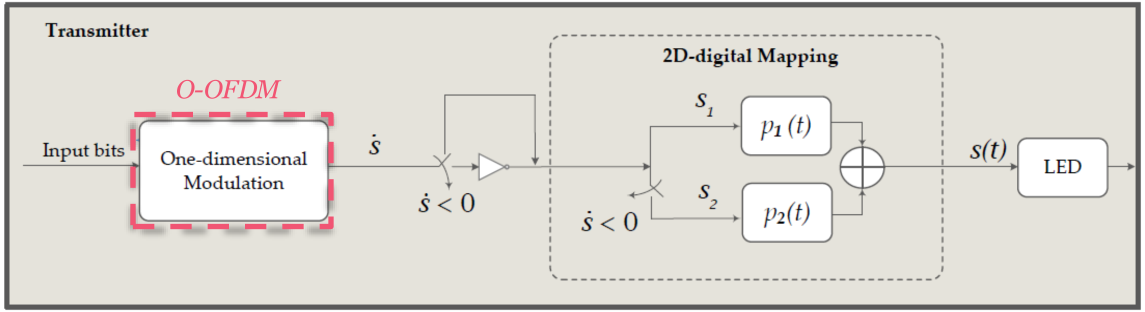
- Asymmetrically clipped optical (ACO)-OFDM: use a **quarter** of the subcarrier to generate a unipolar signal



□ ¼ **SE** of OFDM + **no DC shift**

Adapting OFDM to VLC: orthogonal waveforms

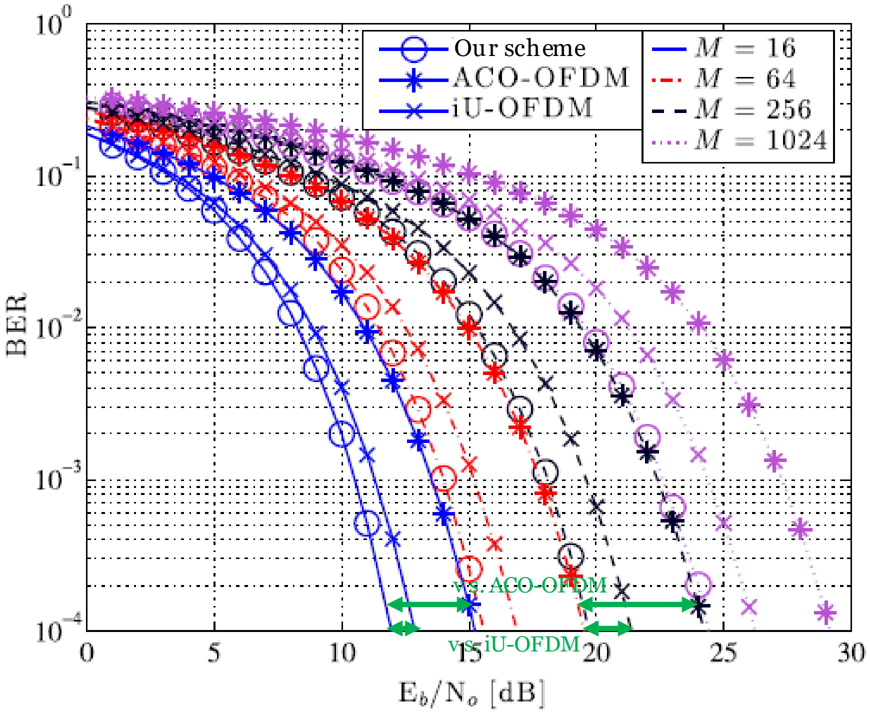
- Use **orthogonal waveforms** to create a **unipolar signal** (remove **dc-shift**) after the **O-OFDM** process



\+ no **dc shift** as ACO-OFDM, but no **clipping** ⭢ **PE**

\- Similar **SE** as ACO-OFDM
\- ⭡ **complexity** of decoding

Performance Analysis I



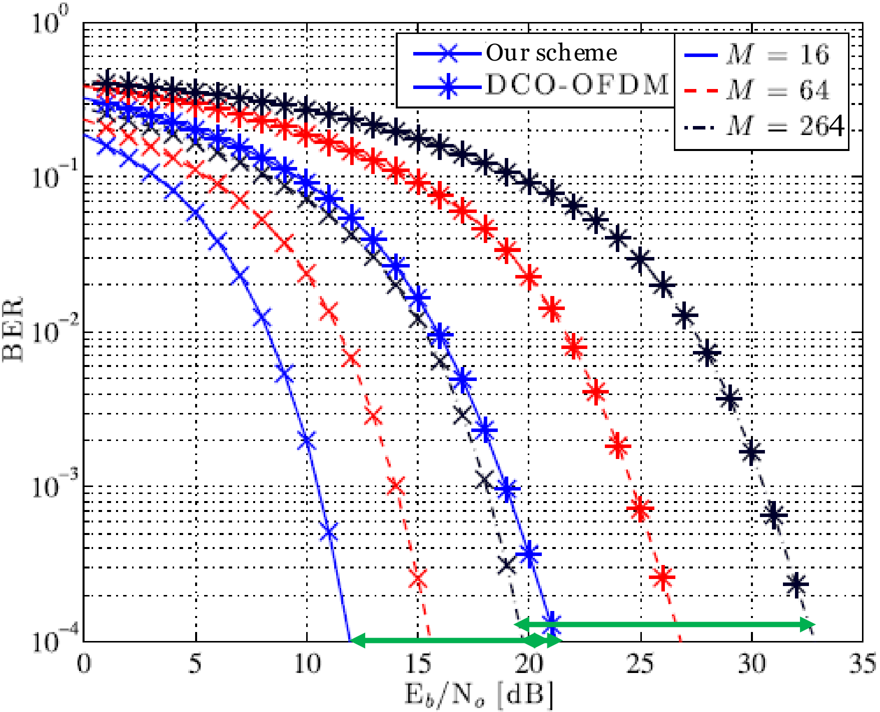
BER performance comparison of our scheme against ACO-OFDM and iU-OFDM for different constellation sizes.

- *Benchmark:* ACO-OFDM and iU-OFDM (improved version of ACO-OFDM, use time domain to create a unipolar signal after **O-OFDM** process)

- Our scheme provides a **better PE** than ACO-OFDM and iU-OFDM (for the **same SE**)
  - ~ **3 to 5 dB** vs. ACO-OFDM
  - ~ **1 to 2 dB** vs. iU-OFDM

- **The transceiver complexity** of our scheme is slightly higher than ACO-OFDM and similar to iU-OFDM.

Performance Analysis II



BER performance comparison of our proposed UOT scheme against DCO-OFDM for different constellation sizes.

- *Benchmark:* DCO-OFDM
- Our schemes provides a **far better PE** than DCO-OFDM, at the **expense** of the **SE**
  - ~ **9 to 13 dB** vs. DCO-OFDM
  - **Half SE** vs. DCO-OFDM
- **Or,** our scheme provides a **better PE** than DCO-OFDM for the **same SE** (comparing our scheme for M=256 vs. DCO-OFDM for M=16)
  - ~ **1.5 dB** vs. DCO-OFDM

Summary

- **Orthogonal-based** waveform design for **VLC**:
  - *Single carrier*: offers the **best existing** **trade-off** between **power efficiency** and **spectral efficiency**
  - *Multi-carrier*: offers a **better power efficiency** than comparable waveform design
- Future work: Utilise our waveform design concept, detailed in [3], for designing **Terahertz** waveform

[1] D. Dawoud, F. Héliot, M. A. Imran, R. Tafazolli, "Power Efficient Three Dimensional Orthogonal Scheme for Visible Light Communication," submitted to Globecom 2021.
[2] D. Dawoud, F. Héliot, M. A. Imran, R. Tafazolli, "A Novel Unipolar Transmission Scheme for Visible Light Communication," IEEE Trans. Commun., vol. 68, no. 4, pp. 2426-2437, Apr. 2020.
[3] D. Dawoud, F. Héliot, M. A. Imran, "Transmitting and receiving symbols via unipolar signals," Int. patent: Patent published, May, 2019.
[4] D. Dawoud, F. Héliot, M. A. Imran, R. Tafazolli, "A Novel Coherent Transmission Scheme for Visible Light Communication," *in proc. IEEE ICC'18*, Kansas City, MO, May 2018.

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Thank You

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