Design and Realization of a GNU Radio based Visible Light Communication Testbed

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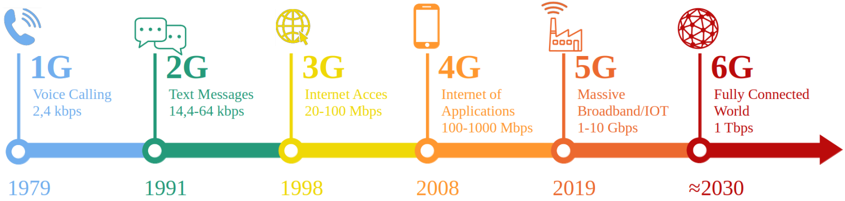
Introduction

General context

- The growing interest in new technologies (IoT, cloud computing) results in a **massive increase** of the **total mobile network traffic** (**370 EB per month** by the end 2027[1])
  $\Longrightarrow$ **frequency raise** to exploit **unused bands** (5G, 6G)
- **Optical Wireless Communication** (OWC) systems constitute a promising **complementary solution** to RF based systems, especially **Visible Light Communication** (VLC) subset
- The concept of Software-Defined Radio (SDR) is applied beyond RF spectrum giving rise to **Software-Defined VLC**



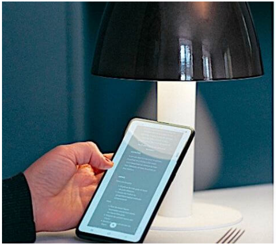
[1] *Ericsson Mobility Report*, Nov. 2021

Introduction

Thesis

- Context: **partnership** with a **lightning manufacturer** HOLIGHT as part of a research project, in order to develop **low data rate** (< 1Mbps) smart lighting solution for **professional and industrial** environment:
  - *indoor localization*
  - *smart city*
  - *e-health*

$\Longrightarrow$ **example**: *table lamp transmitting the restaurant's menu through light variations*[1]



- Theses's objectives:
  - Implementation of a **innovative SDVLC testbed** based on GNU Radio
  - Development of a **VLC open-source library**

[1] https://presselib.com/article/ogeu-holight-lumiere-led-bearn

Outline

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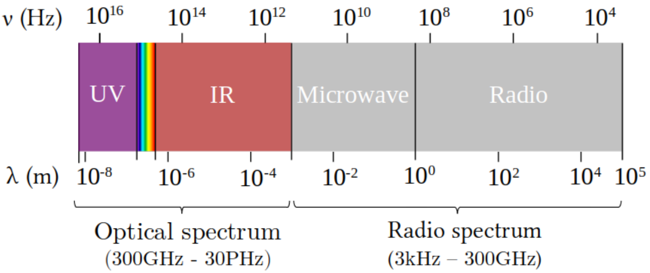
Optical Wireless Communication

Radio / Optical wireless comparison

- OWC: **free-space propagation** of light from IR to UV to transmit information
  $\Longrightarrow$ **complementary solution** to RF systems

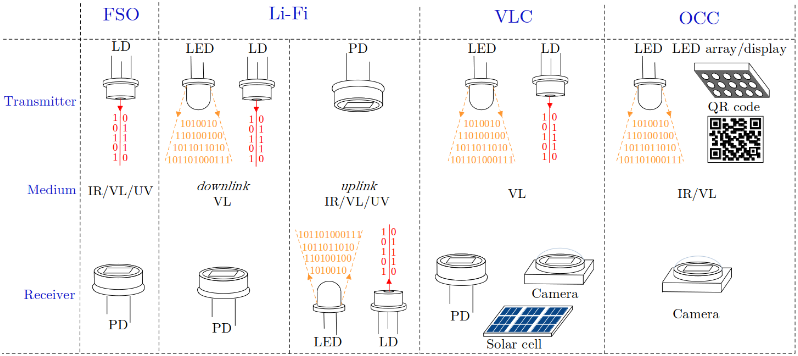


Advantages	Drawbacks
– Higher and non-regulated bandwidth	– Communication blockage
– Higher PHY security	– Ambient light noise
– No EM interferences	– Limited power (health regulation)
– Lower cost	

Optical Wireless Communication

OWC subsets

- OWC can be classified in **different subsets** according to the **system specifications**:



– Free-Space Optics: *long range peer-to-peer communication*

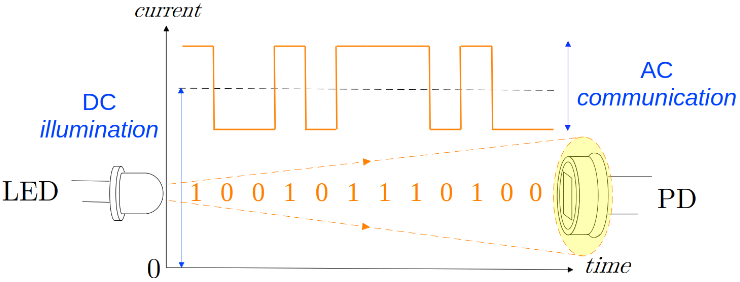
– Light-Fidelity: *bidirectional high data-rate communication*

– Visible Light Communication: *illumination and communication*

– Optical Camera Communication: *low data-rate indoor communication*

Optical Wireless Communication

Visible Light Communication



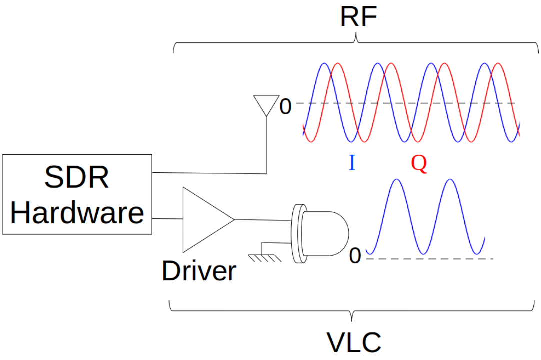
- VLC systems are generally composed of a **LED** as transmitter and a **photodiode** as receiver
- Mostly based on **Intensity Modulation / Direct Detection** (IM/DD)
- Signal frequency > **critical flicker frequency** ($\approx$ 100 Hz) to be imperceptible

Outline

Software-Defined VLC

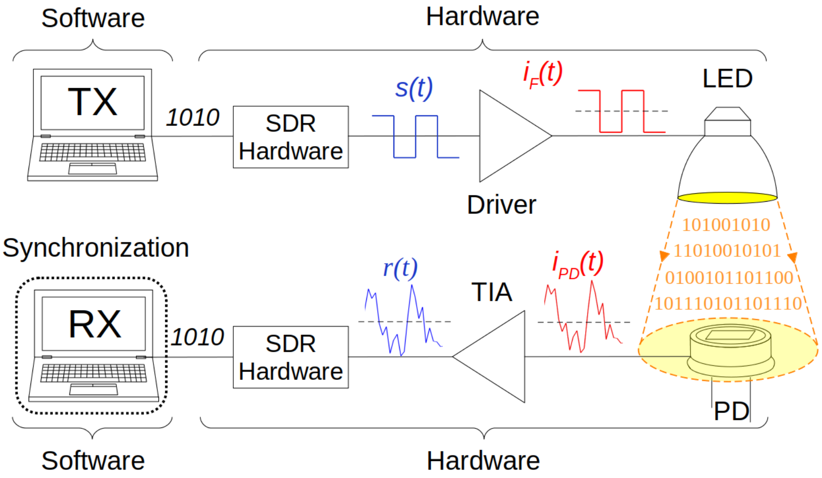
SDR adaptation

- Since SDR was initially designed to the needs of RF systems, **adaptation** is therefore required to perform VLC transmission:
  - Enabling **baseband transmission** (DC transmission)
  - **Optical front-end** (driver + LED/PD) instead of antennas ($\Longrightarrow$ **real** and **positive** signal)



Software-Defined VLC

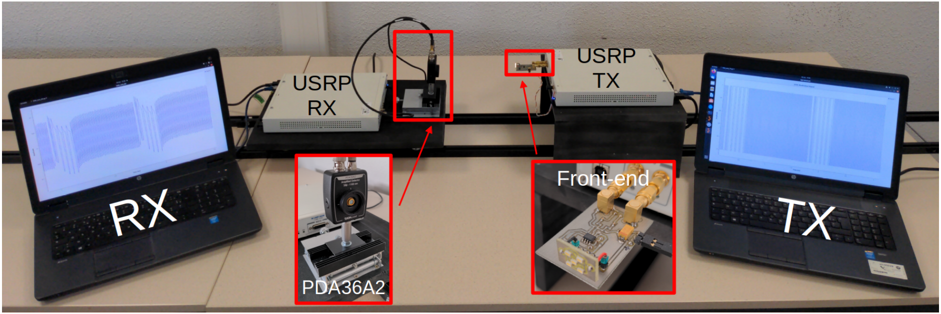
Basic architecture



Outline

SDVLC Testbed

Hardware



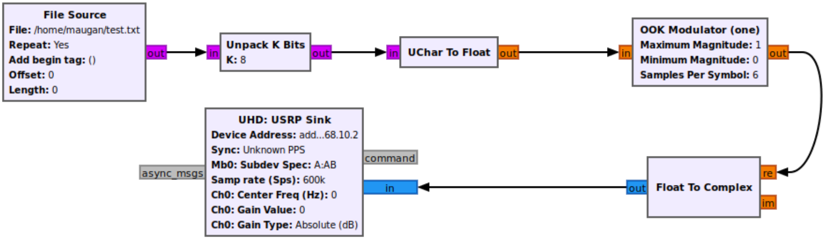
- Based on **USRP 2943R** equipped with **LFTX/LFRX** daughterboards (DC-30 MHz)
- TX: **10 MHz optical front-end** (OP amp. + MOSFET + ×5 white LED)
- RX: Thorlabs **PDA36A2** photodetector (PIN photodiode + TIA)

$\Longrightarrow$ *height, orientation and distance adjustable through a mobile trolley*

SDVLC Testbed

TX Software

- gr-owc [1]: OOT module for **optical channel propagation simulation**
  $\Longrightarrow$ Different modulation schemes available (**OOK**, **2PPM**, **PAM**, **DCO-OFDM**)



100 kbps OOK emission flowgraph based on gr-owc

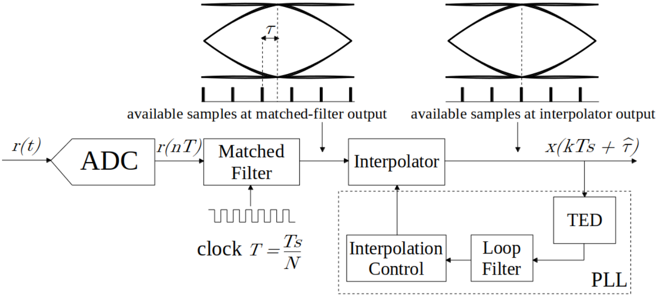
- Working fine in simulation but **not in a hardware implementation**
  $\Longrightarrow$ lack of synchronization at the receiver

[1] https://github.com/UCaNLabUMB/gr-owc

SDVLC Testbed

Timing Synchronization

- Symbol timing synchronizer[1]: samples alignment according to the maximum opening of the eye diagram ($\Longrightarrow$ **timing measurement + timing adjustment**[2])

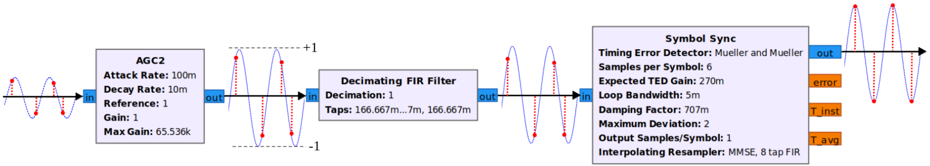


- Matched Filter: *detecting the received signal from the known symbols*
- Interpolator: *moving the asynchronous samples to the desired time instants*
- Timing Error Detector (TED): *producing a signal that is function of the timing error*
- Loop Filter: *filtering the output of TED*
- Interpolation Control: *generating a synchronous clock for the Interpolator*

[1] *Digital Communications: A Discrete-Time Approach*, M. Rice, 2008
[2] *Synchronization Techniques for Digital Receivers*, U. Mengali and A. N. D'Andrea, 1997

SDVLC Testbed

Timing Synchronization



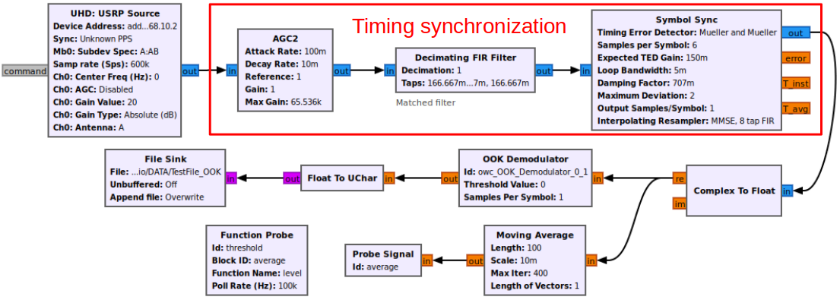
- AGC: *maintains a* ***constant level amplitude***
- Decimating FIR Filter: ***matched filter***
- Symbol Sync: *introduced by Andy Wall in GRCon17*[1] *implementing* ***different TED algorithms*** *(Maximum Likelihood, Mueller & Müller, Zero Crossing...)* ($\equiv$ ***Clock Recovery MM + Polyphase Clock Sync***)

$\Longrightarrow$ **Hervé Boeglen's presentation**: determination of **optimal parameters by simulation** rather than **trial and error** approach

[1] https://www.youtube.com/watch?v=uMEfx_l5Oxk

SDVLC Testbed

RX Software



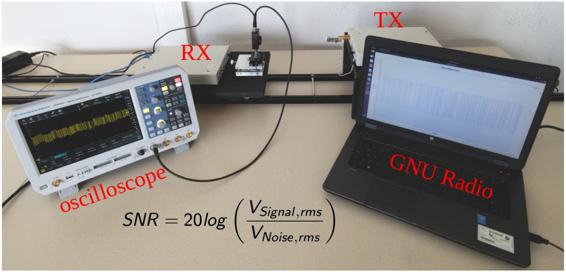
OOK reception flowgraph based on gr-owc with timing synchronization

Outline

Testbed Validation

SNR Measurement

- Performance comparison of **3 TED algorithms** (ML, M&M and ZC) through the evaluation of **Bit Error Rate** with **different SNR**
- SNR measurement:
  - **Spectrum analyser** not adapted to baseband power signal measurement $\Longrightarrow$ use of **oscilloscope** (RMS values)
  - **Ambient noise level** must remains the same along an acquisition $\Longrightarrow$ need a **complete darkness** due to the **high sensitivity** of the photodetector
  - **Different SNR** values are obtained by changing the **communication distance** (from 1.6 to 3.1 meters)



Testbed Validation

BER Measurement

- BER measurement:
  - **Comparison of message sent** with **received bits** recorded in a file (*File sink*) with at least **10 transmission errors**
  - **BER curves** are plotted as a function of Eb/N_0 (= normalized SNR) to **not take bandwidth into account**

$$Eb/N_0(dB) = SNR(dB) - 10 log\left(\frac{Rb}{Bw}\right)$$

Rb: *bit rate*, ***Bw***: *bandwidth*, ***Eb***: *energy per bit*, $\boldsymbol{N_0}$: *noise power spectral density*

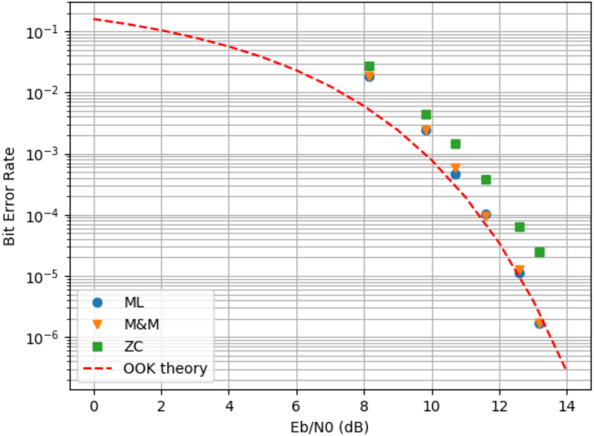
  - **Results** are compared to the **expected error probability of OOK**

$$P_{e-OOK} = \frac{1}{2} erfc\left(\sqrt{\frac{Eb}{2N_0}}\right)$$

erfc: *complementary error function*

Testbed Validation

Results



- As expected **ZC algorithm** is **less effective** than ML and M&M
- **ML** and **M&M** algorithms got **similar and accurate performances** for BER less than 10^{-3}

Outline

Conclusion & Perspectives

Conclusion

- **Adaptation of SDR** to implement a **SDVLC testbed** based on GNU Radio
- **Validation of the testbed** operation through **BER measurement** for different TED algorithms

Perspectives

- **Validation of the testbed** with **Non Light-Of-Sight** (NLOS) transmission
- Integration of **other VLC receivers** (*camera, solar cell*) in the testbed