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Development of IEEE802.15.7 based ITS services using low cost embedded systems

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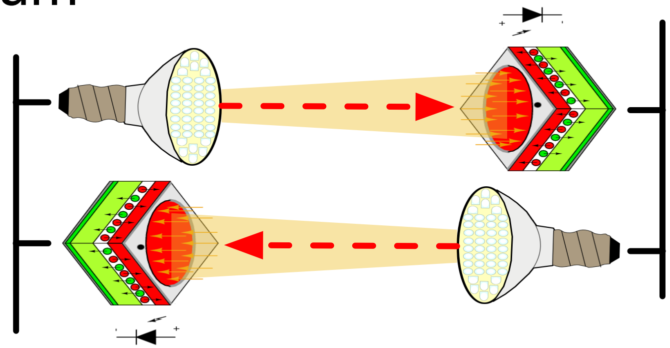
Introduction: Visible Light Communication (VLC)

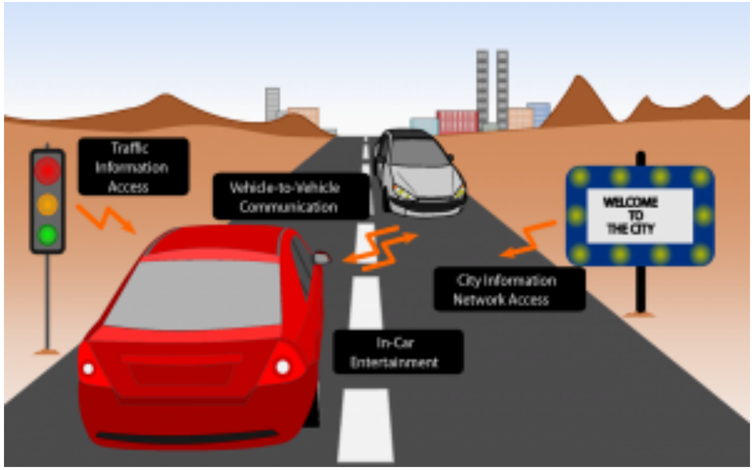
- VLC: **C**ommunication technology using **V**isible **L**ight (380 – 780 nm) as the transmission medium
  - Unlicensed spectrum
  - No electromagnetic interference
  - Security
  - Eye safety, Healthy



- Transmitters: LEDs, Laser
- Receivers: Photodiodes, CMOS sensors
- Channel: free space
- Applications:
  - Indoor Networking Systems
  - Indoor Positioning Systems
  - Underwater VLC
  - <u>Intelligent Transportation Systems</u>

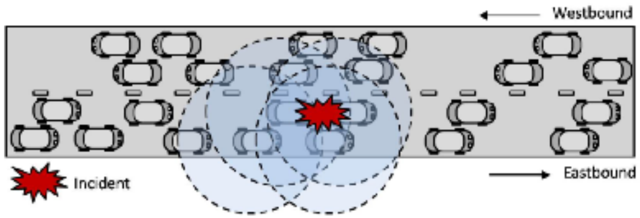
Motivations: VLC inside ITS

- Traffic signals and vehicles are gradually changing from electric light bulbs to LED light.
- LED light infrastructure can enable V2V, V2I, and I2I communications at large scale and low cost.

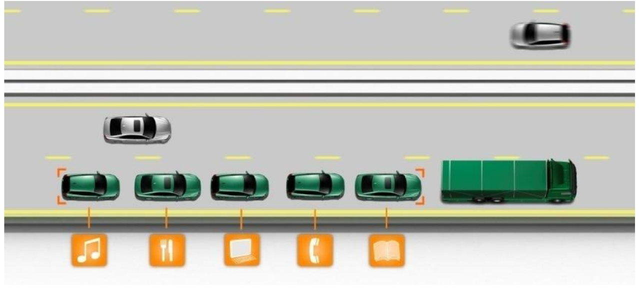


VLC may be a valuable option respect to RF in case of:

- broadcast storm



- platooning

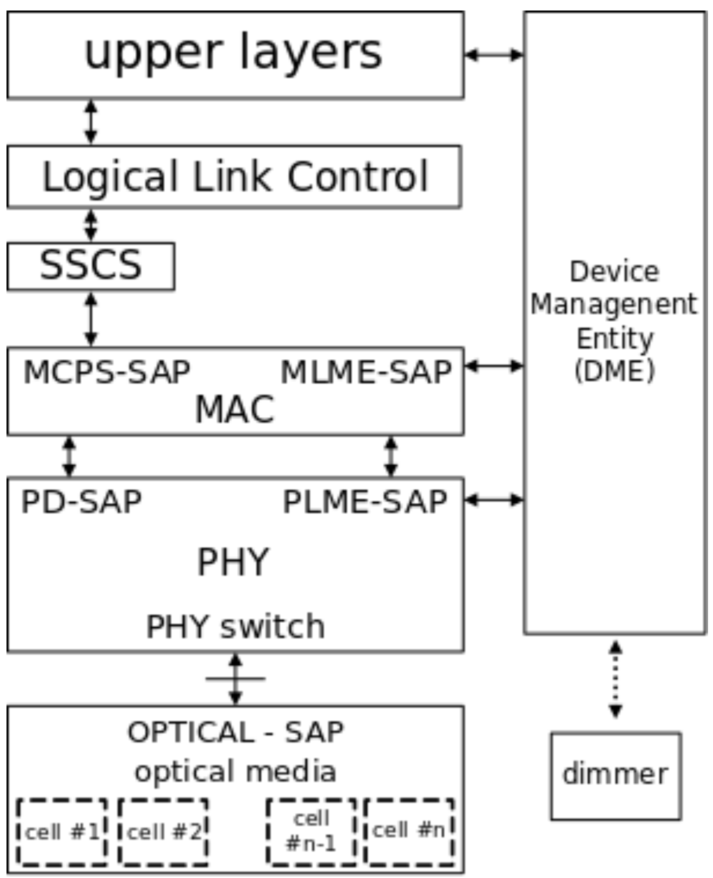


Outdoor VLC challenges:

- Mobility disturbs Line-of-Sight
  - ✓ Optimize lighting positioning
- Sunlight, artificial lights, smog
  - ✓ Use optical filters and optimized electronics

IEEE Std 802.15.7™ - 2011

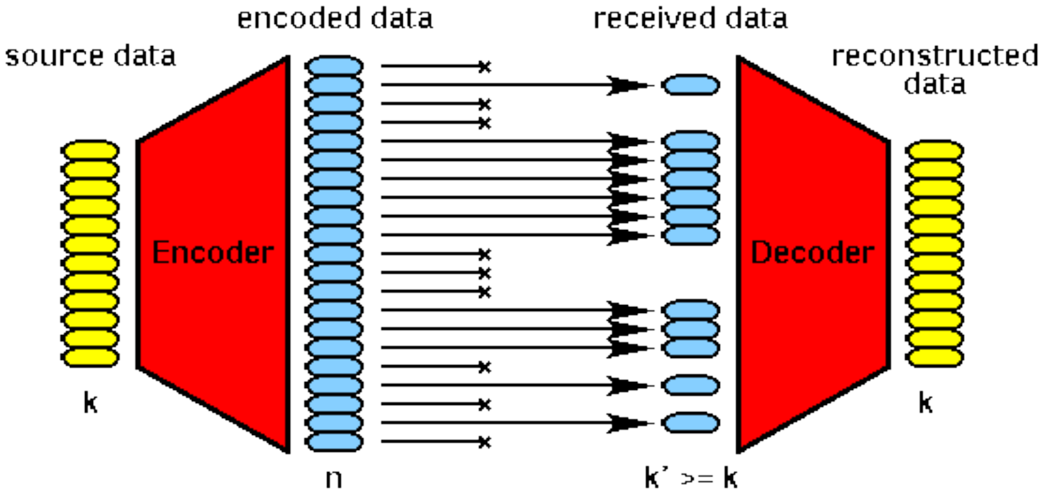
VLC Personal Area Network (VPAN) device



- Standard for local and metropolitan area networks - Short-Range Wireless Optical Communication Using Visible Light
- MAC and **multiple PHY** layers:
  - PHY I (outdoor),
  - PHY II e PHY III (indoor)
- Data rate: 11.67 – 266 kb/s (PHY I) 1.25 – 96 Mb/s (PHY II, PHY III)
- Max MPDU: 1kB (PHY I), 64kB (PHY II, PHY III)
- Topologies: broadcast, star, p2p
- Beaconless and beacon-enabled mode
- Visibility and color function support
- Dimming and flicker-mitigation support

VLC Outdoor: FEC Issue

Outdoor, many accidental physical agents (smog, rain, sudden change of brightness, transiting objects, …) can disturb the communication channel.



Forward Error Correction:

- sender encodes the message in a redundant way by inserting symbols and patterns
- receiver tries to correct the errors, if any, using the known structure of the added data

<u>Different FEC codes are suitable for different conditions.</u>

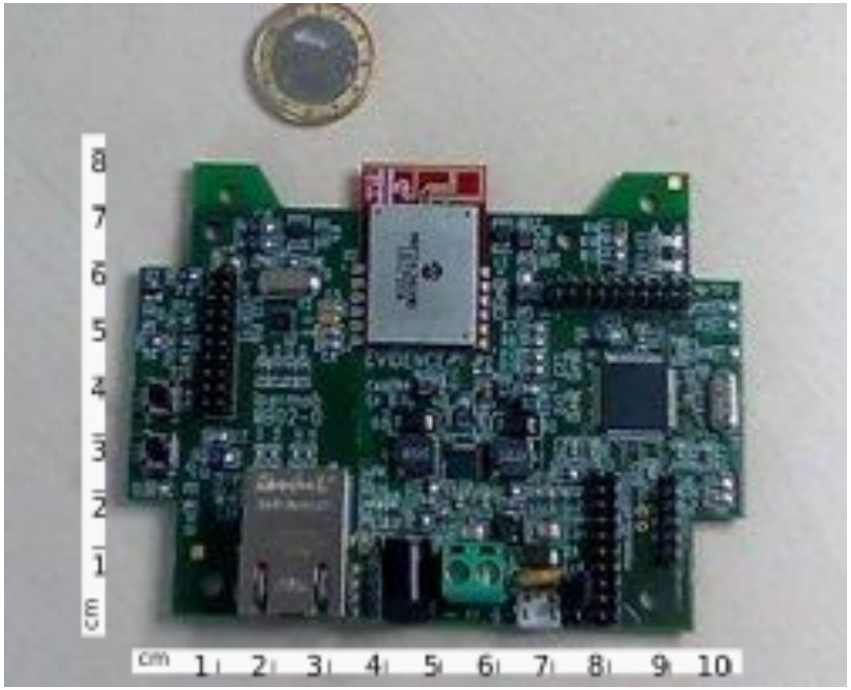
Objective

- Developing a Half-Duplex VLC device
    - Low-cost
    - Off-the-shelf components
    - Standard-compliant (IEEE802.15.7 MAC & **PHY I**)
- Vision: first step towards
    - scalable and pervasive VLC units eligible to be easily integrated in more complex systems like ITS.

Methodology

- Study of the standard
- Developing HW and SW prototype
- Experimental evaluation:
  - Test Bench Measurements
  - Open Field Measurements

Tools: SEED-EYE Board



- **W**ireless **S**ensor **N**etwork node for C-ITS
- In house developed (part of the IPERMOB ITS project)
- MCU: Microchip PIC32MX795F512L
  - 80 MHz
  - 512 K Flash ROM, 128 K RAM
  - Interfaces: SPI, UART, I2C, CAN
- **IEEE 802.15.4** interface with Microchip MRF24J40MB RF transceiver
- **IEEE 802.3** interface for wired LAN communications

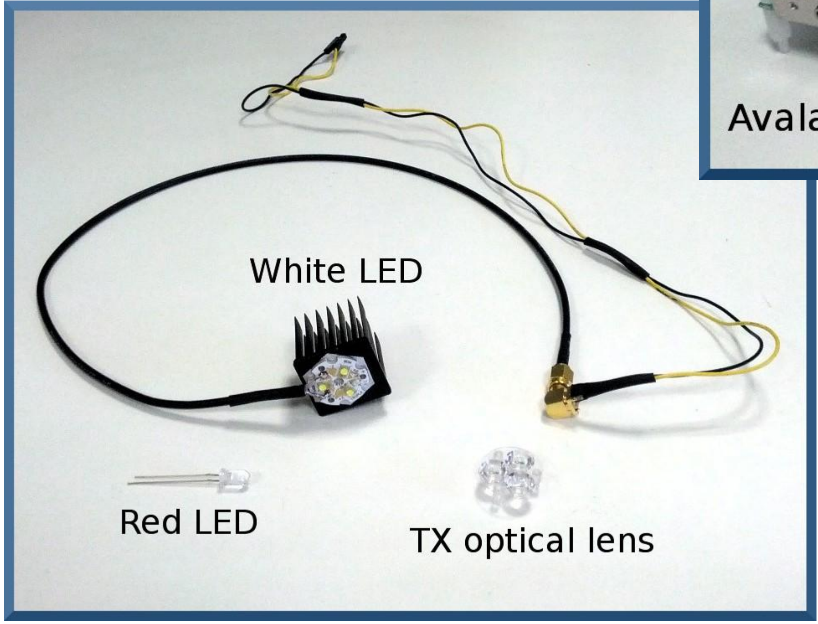
Tools: SW development environment

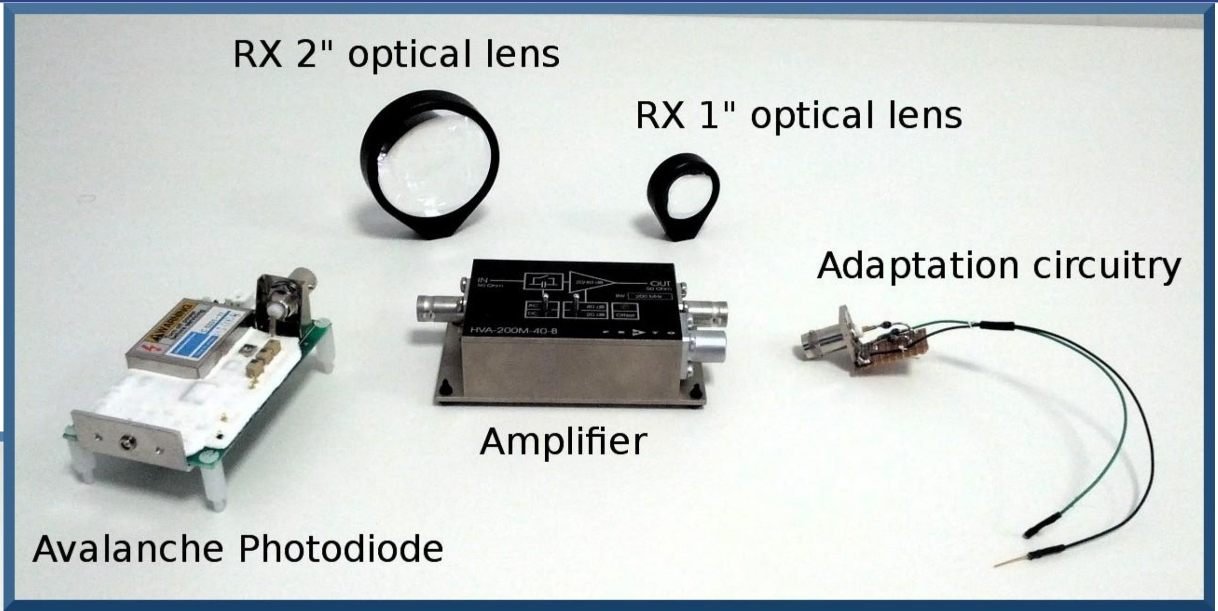
- Open source Free **Real-Time Operating System** OSEK/VDX compliant (Standard for automotive embedded systems)
- Highly modular, small footprint: minimal 1-4 Kb Flash real-time kernel, for 8 to 32 bit MCPU
- Portable APIs for different microcontrollers (tasks, events, alarms, resources, application modes, semaphores, ...)

- Microchip Integrated Development Environment
  - Programming directly the MCU without OS

Tools: Optical components

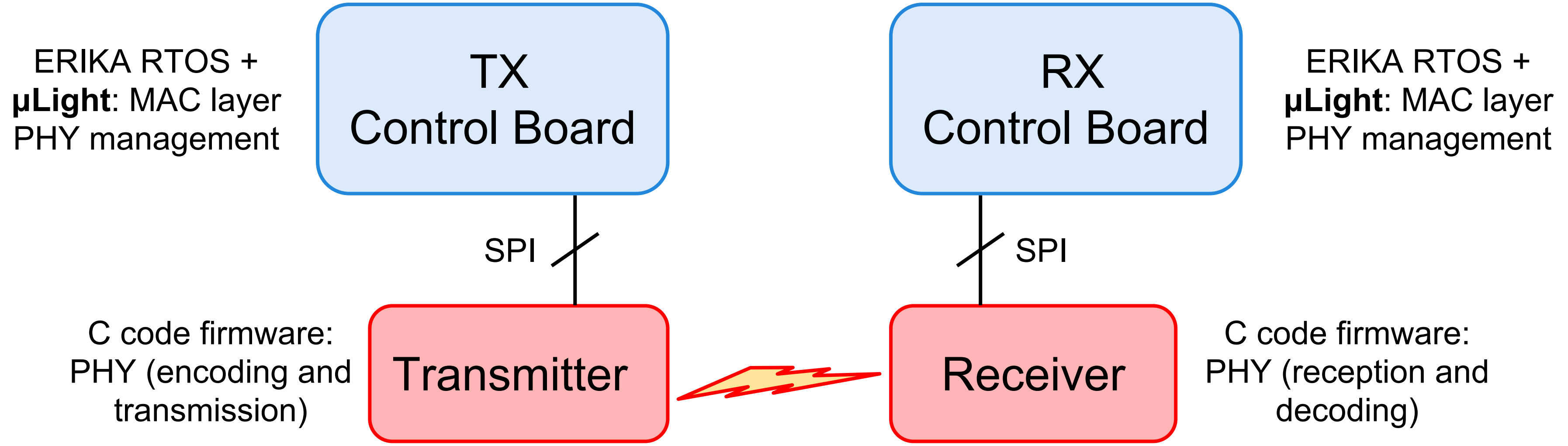
TRANSMITTER

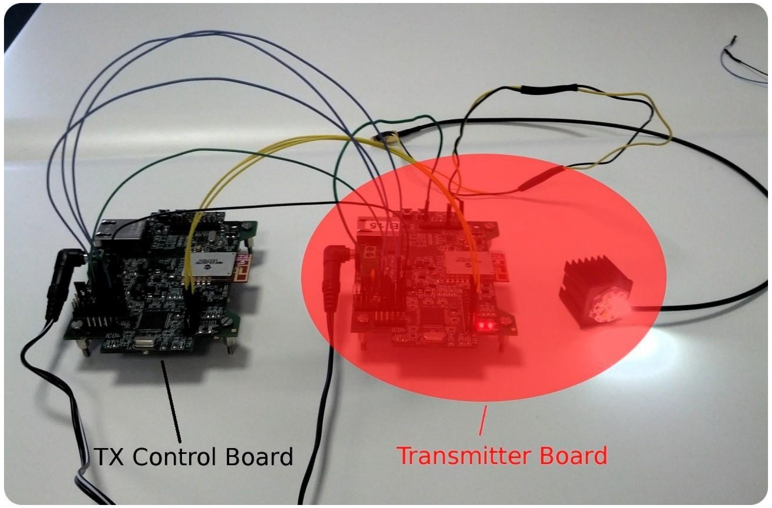


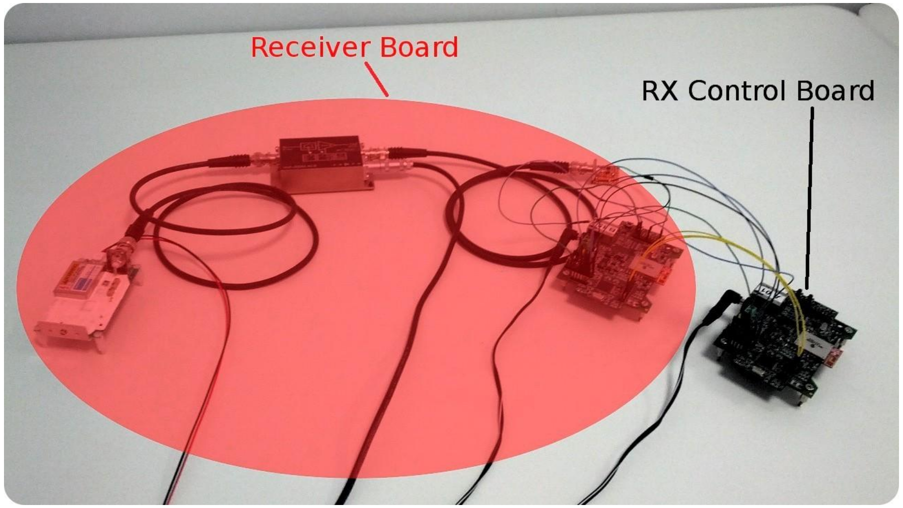


RECEIVER

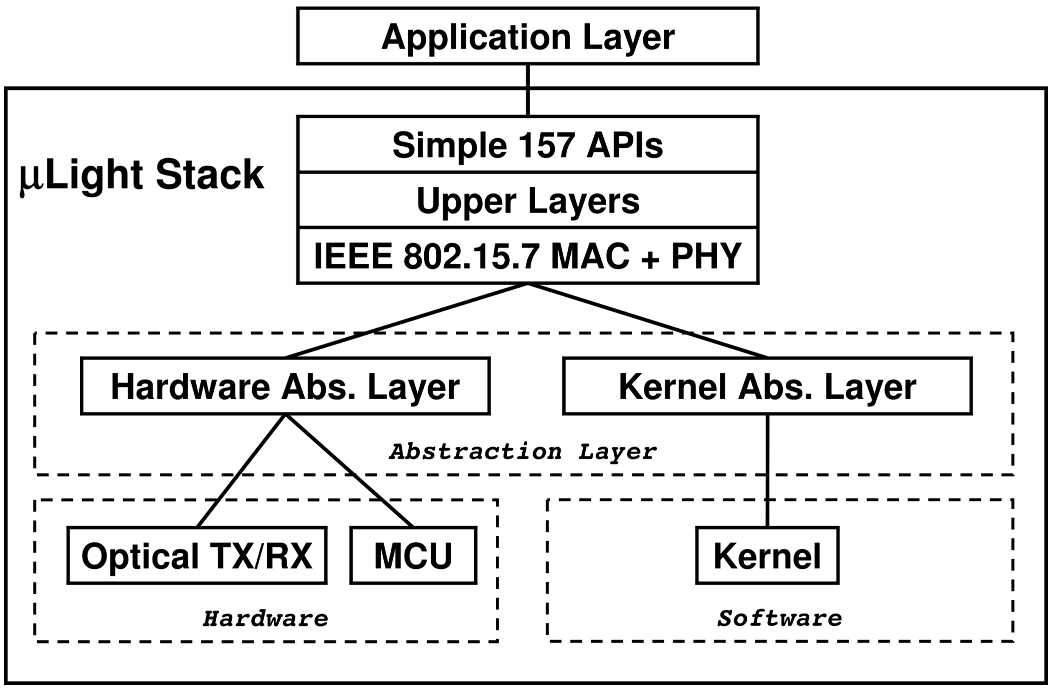
System Overview







Control Board: µLight stack for Erika RTOS



- **µLight** implements IEEE 802.15.7 MAC layer and PHY management tasks on the Control Boards
- Library *ad hoc* developed for Erika RTOS
- A driver for Tx/Rx devices is included
- Inspired by µWireless (IEEE 802.15.4 library for ERIKA RTOS)
- Shipped with a high level API library

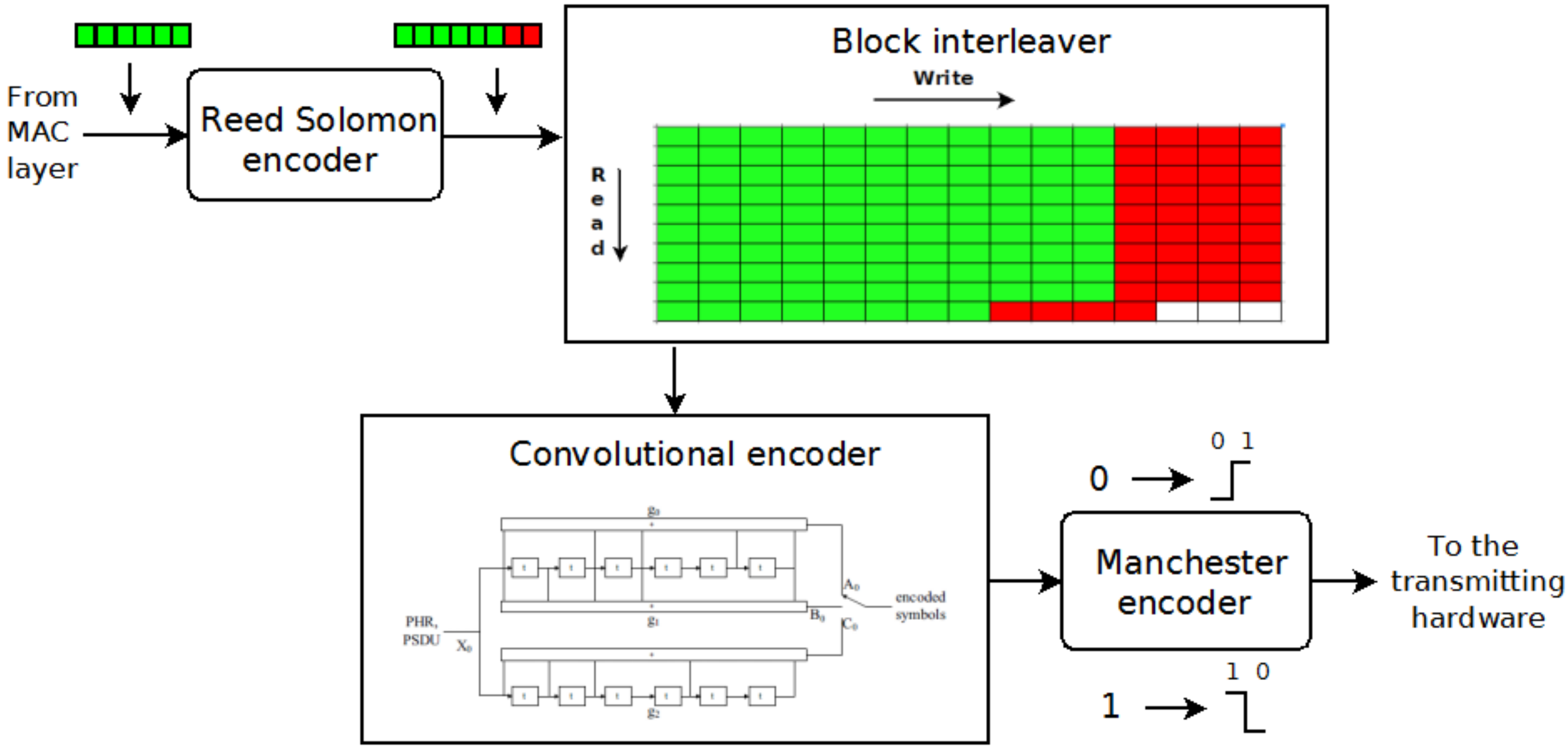
Tx/Rx Devices: implemented tasks

- The firmware developed in C enables the following tasks @ PHY layer:
  - ✓ Activation and deactivation of the VLC transceiver
  - ✓ Wavelength Quality Indicator for received frames
  - ✓ Data transmission and reception
  - ✓ Error correction
  - ✓ Synchronization

Tx/Rx Devices: the PHY I specification

- IEEE 802.15.7 PHY I is targeted towards applications requiring low data rates
- Header shall be sent at 11.67 kb/s if the 200 kHz optical clock rate is selected or at 35.56 kb/s if the 400 kHz optical clock rate is selected.
- <u>Support for 11.67 kb/s at 200 kHz optical clock is mandatory.</u>

IEEE 802.15.7 reference channel coding for PHY I



Tx/Rx: implemented coding support for error correction

Transmitter

Modulation	RLL code	Optical clock rate	Forward Error Correction		Data Rate [kbps]
			Outer Code	Inner Code	
OOK	Manchester	200 kHz	R-S (15,7)	CC (¼)	11.67
			R-S (15,11)	CC (⅓)	24.44
			R-S (15,11)	CC (⅔)	48.89
			R-S (15,11)	none	73.30
			none	none	100
VPPM	4B6B	400 kHz	R-S (15,2)	none	35.56
			R-S (15,4)	none	71.11
			R-S (15,7)	none	124.4
			none	none	266.6

Receiver

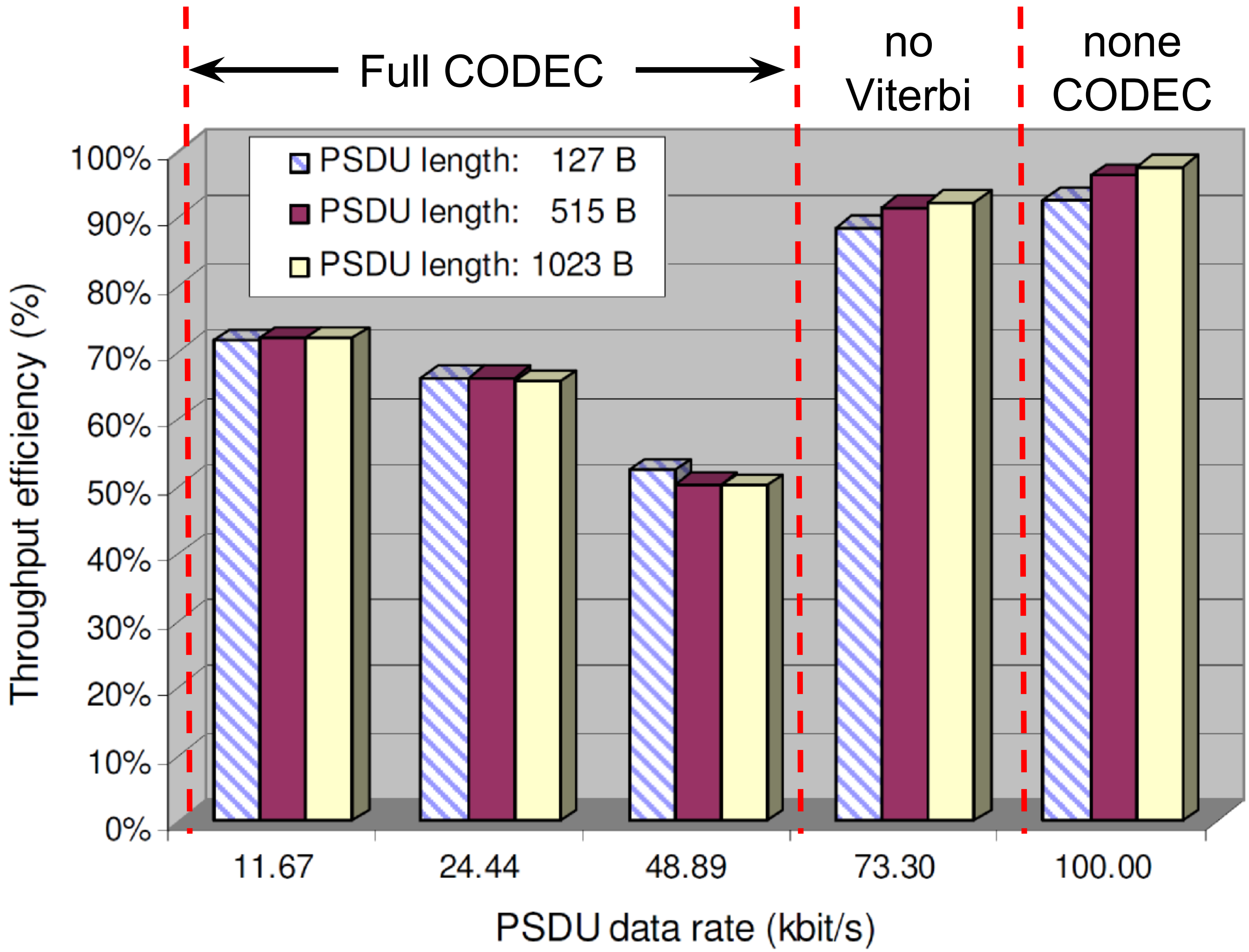
DECODER	
Viterbi	R-S (15,7)
Viterbi	R-S (15,11)
Viterbi	R-S (15,11)
none	R-S (15,11)
none	none
none	R-S (15,2)
none	R-S (15,4)
none	R-S (15,7)
none	none

Test bench: CODEC processing times

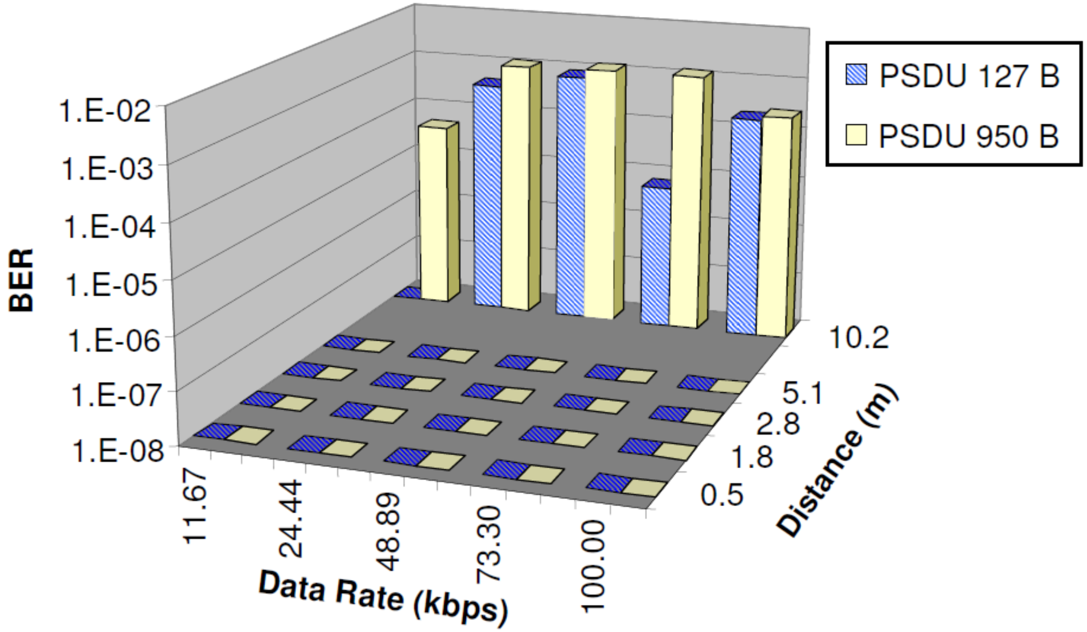
Board	Task	Processing Time (μs)
Transmitter	SPI optical transmission ISR	2.6
	RS(15,7) block encoding	20
	RS(15,11) block encoding	16
Receiver	Viterbi single iteration	15
	Viterbi complete decoding *	0.27×10^6
	RS(15,7) block decoding without errors	32
	RS(15,7) block decoding with errors	72
	RS(15,7) complete decoding with errors **	0.021×10^6
	RS(15,11) block decoding without errors	18
	RS(15,11) block decoding with errors	40

(*)=1023 B PSDU + RS(15,7); (**)=1023 B PSDU.

Test bench: Throughput efficiency



Error-free range measurements: BER



- Error-free communication was achieved up to 5.1 m
- Communications at 10.2 m showed some errors: BER <10^{-3}

Conclusion

- A half-duplex VLC prototype as first step for C-ITS applications has been realized.
- The device implements PHY I and MAC layers such as conform to the IEEE802.15.7 standard.
- Efficient channel utilization at highest bit rates, when convolutional codes are not used.
- Faster electronic devices are needed to handle in a suitable way the error correction protocols prescribed by IEEE802.15.7 at slow rates.
- The quality of signal transmission is acceptable within 10 meters.
- Improvements of the receiver devices are needed (photodiodes with larger active area and optimized optical systems).
- At now, referring to ITS domain,only I2I communications services are feasible with the current prototype.

Work in Progress

- Transferring the Optical Transmitter/Receiver functions on a FPGA (HW architectures with parallel processing).
- Full Duplex System with full IEEE802.15.7 functions
- Implement the adaptation layer between IPv6 and IEEE802.15.7 to allow the access of VLC technology to the Internet of Things infrastructure.
- Implement the vertical handover between VLC and other media: R/F, IR, ...
- Promote the standard development of VLC for C-ITS at ISO and ETSI Working Groups

Thank you for your attention !

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NETWORKS OF EMBEDDED SYSTEMS

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