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

Alessio Bellè(*) , Mariano Falcitelli(**), Matteo Petracca(**), Paolo Pagano(**)

(*) TeCIP Institute - Scuola Superiore Sant'Anna - Pisa, ITALY
(**) CNIT - National Laboratory of Photonic Networks Pisa, ITALY
Introduction: Visible Light Communication (VLC)

- **VLC**: Communication technology using Visible Light (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
  - Intelligent Transportation Systems
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
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

**Different FEC codes are suitable for different conditions.**
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

- **Wireless Sensor Network 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**
- White LED
- Red LED
- TX optical lens

**RECEIVER**
- RX 2" optical lens
- RX 1" optical lens
- Avalanche Photodiode
- Amplifier
- Adaptation circuitry
System Overview

ERIKA RTOS + μLight: MAC layer PHY management

TX Control Board

C code firmware: PHY (encoding and transmission)

SPI

Receiver Board

RX Control Board

C code firmware: PHY (reception and decoding)

Transmitter Board

RX Control Board

Transmitter

Receiver
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
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
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.

- Support for 11.67 kb/s at 200 kHz optical clock is mandatory.
IEEE 802.15.7 reference channel coding for PHY I

From MAC layer → Reed Solomon encoder → Block interleaver → Convolutional encoder → Manchester encoder → To the transmitting hardware

0 → 01
1 → 10
Tx/Rx: implemented coding support for error correction

<table>
<thead>
<tr>
<th>Modulation</th>
<th>RLL code</th>
<th>Optical clock rate</th>
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<th>Optical clock rate</th>
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<tbody>
<tr>
<td>OOK</td>
<td>Manchester</td>
<td>200 kHz</td>
<td>VPPM</td>
<td>4B6B</td>
<td>400 kHz</td>
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<tr>
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<th>Transmitter</th>
<th>Receiver</th>
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## Test bench: CODEC processing times

<table>
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<th>Board</th>
<th>Task</th>
<th>Processing Time (μs)</th>
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</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>SPI optical transmission ISR</td>
<td>2.6</td>
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<tr>
<td></td>
<td>RS(15,7) block encoding</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>RS(15,11) block encoding</td>
<td>16</td>
</tr>
<tr>
<td>Receiver</td>
<td>Viterbi single iteration</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Viterbi complete decoding *</td>
<td>0.27 x 10^6</td>
</tr>
<tr>
<td></td>
<td>RS(15,7) block decoding without errors</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>RS(15,7) block decoding with errors</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>RS(15,7) complete decoding with errors **</td>
<td>0.021 x 10^6</td>
</tr>
<tr>
<td></td>
<td>RS(15,11) block decoding without errors</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>RS(15,11) block decoding with errors</td>
<td>40</td>
</tr>
</tbody>
</table>

(*)=1023 B PSDU + RS(15,7); (**)=1023 B PSDU.
Test bench: Throughput efficiency

Throughput efficiency (%)

PSDU data rate (kbit/s)

11.67  24.44  48.89  73.30  100.00

PSDU length: 127 B
PSDU length: 515 B
PSDU length: 1023 B

Full CODEC  no Viterbi  none CODEC
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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Mariano Falcitelli

mariano.falcitelli@cnit.it

http://rtn.sssup.it