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Miller Code Usage in Visible Light Communications under the PHY I layer of the IEEE 802.15.7 standard

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Introduction to VLC

- Visible Light Communications (VLC) represents the usage of LEDs for both illumination and wireless data transmission;
- IEEE 802.15.7 draft standard (2011);
- World-wide unregulated, almost unlimited spectrum enables high data rates (3 Gbps - 2014);
- Safe for the human body and for electronic equipment (unlike RF or IR);
- Ubiquitous technology with reduced implementation cost;
- VLC in the Intelligent Transportation System (ITS) - based on LED vehicle lighting systems, street lighting, traffic lights.

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VLC in the ITS

- I2V & V2V have the potential to address up to 81% of the traffic accidents.
- VLC is an alternative and/or a complement to RF based communication in several scenarios (e.g. high traffic densities lead to increased latencies, unacceptable for a reliable safety system).
- VLC could reduce the load on the RF channels;

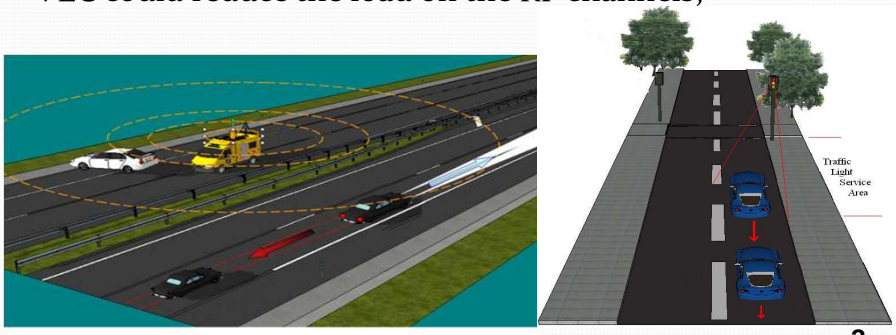

Fig. 1 – Scenarios for VLC usage in the ITS

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VLC modulations and coding

- Intensity Modulation (IM) is considered to be the most appropriate modulation technique for VLC;
- IEEE 802.15.7 specifies for outdoor application (PHY I) the usage of OOK with Manchester coding (11.67 – 100 kbps);
- Miller code has similar characteristics but seems better suited for MIMO applications (Fig. 2);

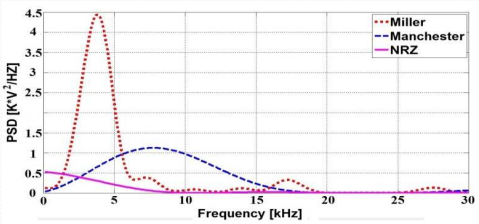

Fig. 2 – PSD for NRZ, Manchester and Miller code at 11.67 kHz

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Evaluation of multi-channel capabilities

- For the Manchester code, the five carriers overlap, making the separation quite difficult and introducing decoding errors.
- For the Miller code, the five channels can be well distinguished.

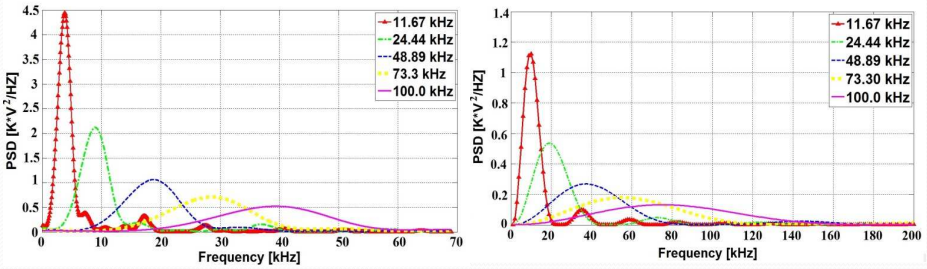

Fig. 3 – Simulation for five channels configuration, using the Miller respectively the Manchester code.

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Miller Code Flickering Evaluation

- Flickering represents the light intensity fluctuation caused by the modulation technique;
- Flickering is prevented when the light intensity changes within the Maximum Flickering Time Period (MFTP=5ms);
- The brightness intensity at byte level is determined (Fig. 4);
- The brightness intensity at MFTP level is determined (Fig. 5);

$$Perceived\ light(\%) = 100 \times \sqrt{\frac{Measured\ light\ (\%)}{100}}$$

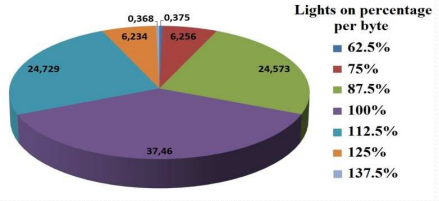

Fig. 4 – Bytes percentage for different brightness intensities.

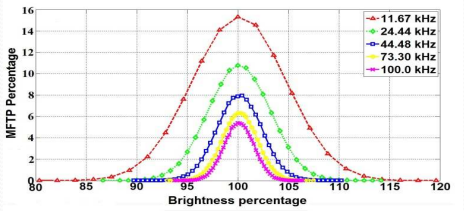

Fig. 5 – Percentage of MFTP for different brightness percentages.

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VLC System Hardware Implementation

- A VLC system has been developed (Fig. 7);
- The emitter-receiver link has been tested using the frame illustrated in Fig. 6.

Fig. 6 – Structure of the data frame

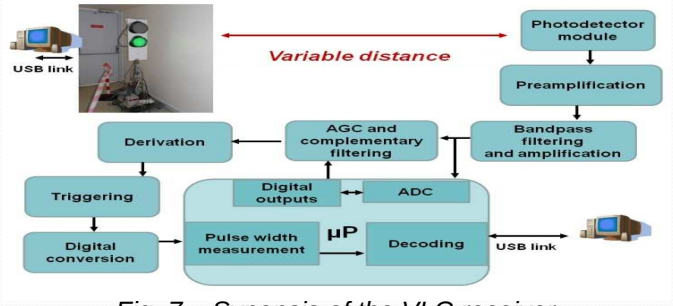

Fig. 7 – Synopsis of the VLC receiver

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BER Evaluation - Experimental Results

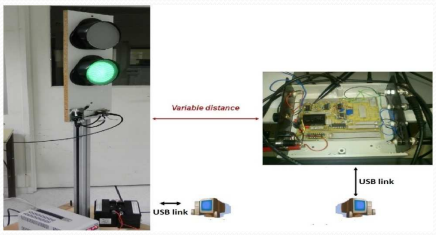

Fig. 8 – Hardware VLC system

- Tests were performed under various conditions, to determine the BER for the two codes.
- The similar performances of the two codes are experimentally confirmed;

Table I – Results at a 15 kHz modulation frequency

Emitter-Receiver Distance	Data coding	BER	Testing conditions
1 – 50 m	Manchester Miller	$<10^{-7}$	Outdoor with daylight
1-20 m	Manchester Miller	$<10^{-7}$	Indoor with artificial light

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Conclusions

- A comparative analysis between the Manchester and the Miller codes was performed;
- The Miller code has better channel usage;
- The Manchester code has better flickering performances, however the flickering induced by the Miller code is unperceivable;
- The two codes had similar BER results (experimentally confirmed);
- Since the Manchester and the Miller codes are similar in BER performances, but the latter has better channel usage, we can state that the Manchester code is adequate for single channel communications, whereas the Miller code is better suited for MIMO applications.

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Miller Code Usage in Visible Light Communications under the PHY I layer of the IEEE 802.15.7 standard

Thank you!

Questions?

- Acknowledgement - This work was supported in part by the University of Versailles Saint-Quentin and Valeo Industry. A part of the financial support is granted by the Fond Unique Interminsteriel (FUI) project named Co-Drive, supported by the Pôle de Compétitivité Mov'eo.
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17^{20}	**Sorin ZOICAN** **Marius VOCHIN** Politehnica University of Bucharest, *Romania*	*On Implementing Packet Inspection using CUDA Enabled Graphical Processing Units*
17^{40}	**Alin-Mihai CAILEAN** **Barthélemy CAGNEAU** **Luc CHASSAGNE** Université de Versailles, *France* **Mihai DIMIAN** **Valentin POPA** Ștefan cel Mare University of Suceava, *Romania*	*Miller Code Usage in Visible Light Communications under the PHY I layer of the IEEE 802.15.7 standard*
18^{00}	**Adelina OCHIAN** **George SUCIU** Beia Consult International, *Romania* **Octavian FRATU** **Carmen VOICU** Politehnica University of Bucharest, *Romania* **Victor SUCIU** Beia Consult International, *Romania*	*An Overview of Cloud Middleware Services for Interconnection of Healthcare Platforms*
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The last sentence of section 3 should be revised. A mathematical relationship cannot determine human sensation.