Evaluation of the noise effects on Visible Light Communications using Manchester and Miller coding

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***Abstract*— This paper presents the investigation results concerning the negative effects of noise on the data signal in the case of Visible Light Communications (VLC). The motivation of this work was to offer a better understanding of the modifications of the data pulse in the presence of noise. Better understanding of the noise effect on the pulse width can help mitigate it and improve the communication performances. The paper also aims to make a comparative evaluation of two coding techniques used for outdoor VLC: the Manchester code as the code specified by the IEEE 802.15.7 standard in the case of outdoor applications using On-Off-Keying (OOK) modulation and the Miller code, as a possible alternative in Multi Input Multi Output (MIMO) applications. Simulations are performed on messages coded using the two codes for different levels of noise. It seems that in the case of digital signal processing (DSP), the Miller code pulse is less affected by distortions caused by noise. However, in the case of the Manchester code, the higher error tolerance compensates for the pulse distortions. Regarding the Bit Error Ratio (BER), the two codes exhibit similar performances.**

Keywords*— *delay modulation; intensity modulation; Manchester coding; noise effect; visible light communication.

I. INTRODUCTION

Nowadays, the modern society presents a growing demand for wireless communications technologies. This demand is encountered in more and more application fields. Such an application area is the Intelligent Transportation System (ITS). ITS plans to use the wireless data transfer for the so called communications-based safety applications. In these applications, wireless technologies are used to enable Vehicle-to-Vehicle (V2V) and Infrastructure-to-Vehicle (I2V) communications with the purpose of increasing the safety and the efficiency of the transportation system. The efforts towards the development of the ITS were confirmed with the publication of the IEEE 802.11p standard [1] for vehicular safety communication. Even if for many years, the radio frequency (RF) based solutions were considered the dominating wireless communication technology, in the recent years, VLC came as an alternative emerging technology which could be more appropriate in certain scenarios. Such a scenario is encountered in a high traffic density areas, where the increased number of notes that are using the communication medium leads to increased latencies [2, 3], which are unacceptable in traffic safety applications.

The VLC technology takes advantage of the recent efforts made towards the development of the solid state lighting devices [4], such as Light Emitting Diodes (LEDs), which are expected to replace the classical lighting sources in the near future [5, 6]. Besides lighting, LEDs are capable of rapid switching enabling them to add communication to the lighting function. Concerning the VLC receivers, they use light sensing elements which can be photodetector elements or camera systems. Camera systems have the advantage of a wide reception angle. However, the performances of such systems are closely related to the camera's number of frames per second (fps). High speed cameras are able to provide decent BER performances, but due to the high price, their usage is limited mostly to laboratory prototypes.

The usage of VLC for transportation related applications was first considered in 1998 [7, 8], and since then much effort has been made on this topic. Currently, there are numerous communication systems that use VLC for I2V [9, 10] or for V2V [11, 12] communication, thus proving their reliability. Regarding the requirements imposed for the Vehicular Ad-hoc Networks [13], VLC is considered to be able to satisfy them even in real working conditions [14]. VLC is also compatible with platooning as demonstrated in [15]. Even if the communication range of these systems is not as long as for those using RF solutions, multi-hop VLC has proven that by combining short and medium range communications, the overall communication distance can be increased [16]. At this point, VLC usage for transportation related applications involves relatively low data rates, from tens of kbps to a few Mbps.

The importance of VLC has been certified with the standardization of the wireless optical communications using visible light by the IEEE 802.11.7 standard [17]. The standard comes with three physical layers for different applications and data rates requirements. Within the standard, the PHY I is intended for outdoor, long-range, low data rate applications such as I2V and V2V communication.

Considering the growing interest towards VLC, this paper presents the simulation results concerning the negative effects

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of noise on the received data signal, mainly focusing on the pulse width distortions. The analysis is performed on messages coded using the Manchester and the Miller codes. The simulations were carried using a digitally processed signal. As far as we know, this is the first paper that approaches the issues concerning the noise effect on VLC at the pulse level, and the distortion it produces. Within the paper, the performances of the Manchester and Miller codes are evaluated. The paper also proposes a VLC receiver architecture based on DSP.

II. THE NOISE INFLUENCE ON THE VLC CHANNEL

Intensity Modulation (IM) is considered to be the most appropriate modulation technique for optical communications [18], which is also the case of VLC. In IM, the desired waveform is modulated on the instantaneous power of the carrier. At the receiver side, the data from the modulated light beam is extracted by using Direct Detection (DD). The photodetector produces an electrical current proportional to the incident optical power which is transformed into a voltage by a transimpedance circuit. Next, the signal passes through several filtering and amplification stages until the data signal is reconstructed.

However, the incident power contains not only the data signal but also noise. The outdoor VLC channel is considered to be extremely noisy. Sun light, street light and vehicle lighting systems represent major background noise sources for VLC. These high noise interferences are corroborated with low-level signals due to signal degradation with the distance. The weather conditions, such as fog or rain, also have a negative impact on the VLC data signal. Furthermore, due to the dynamic nature of the traffic, in such applications, the VLC receiver will experience high variations of the SNR. Different mitigation mechanisms such as narrow angle receivers, optical filters, or different signal processing techniques are used at the receiver side. However, high levels of noise affect the quality of the communication. Therefore, an analysis of the noisy optical channel effects on the data signal is strongly required.

The VLC performances are strongly influenced by the communication channel. A VLC channel can be modeled as a baseband linear system, with instantaneous power $X(t)$, output photocurrent $Y(t)$ and impulse response $h(t)$ [18]. The channel is subject to signal independent additive noise as shown in Fig. 1 and expressed in eq. 1.

$$Y(t) = RX(t) \otimes h(t) + N_{Total}(t) \tag{1}$$

where R is the detector responsively (A/W), and $\otimes$ indicates the convolution.

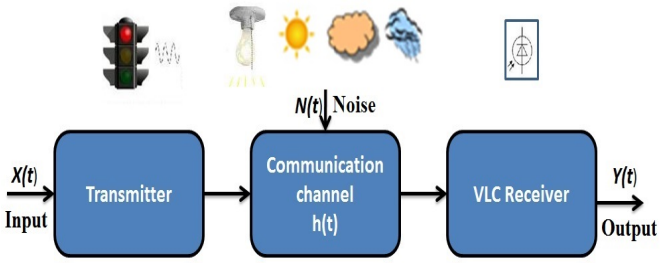

Fig. 1. Simplified VLC channel model.

The noise affecting the VLC channel (N_{Total}) contains a shot noise component and a thermal noise component, as expressed in eq.2

$$N_{Total} = \sqrt{N_{shot}^{\ 2} + N_{thermal}^{\ 2}} \tag{2}$$

The shot noise (eq. 3) is proportional to the total optical noise power incident on the receiver. The effect of the shot noise can be minimized by using optical filters, but still this remains a perturbing noise source, limiting the communication's performances. In day-time outdoor communications, shot noise is the dominant noise component.

$$N_{shot} = 2qIB \tag{3}$$

where q is the electronic charge ($q=1.602 \cdot 10^{-19}$ coulombs), B is the detector bandwidth and I is the produced photocurrent.

The thermal noise (eq. 4) is represented by the preamplifier noise, and is the predominant noise source in the absence of background light.

$$N_{thermal} = \frac{4KTBN_{circuit}}{R} \tag{4}$$

where K is Boltzmann's constant ($k=1.381 \cdot 10^{-23}$), T is the temperature, $N_{circuit}$ is the circuit noise, and R is the load resistance.

Both the shot noise and the thermal noise are signal-independent and Gaussian. Under these conditions, the total noise affecting the VLC channel can be modeled as signal-independent Gaussian noise.

Regarding the coding techniques, the IEEE 802.15.7 standard for wireless optical communications using visible light defines for the PHY I outdoor applications, the utilization of On-Off-Keying (OOK) with Manchester coding, with data rates from 11.67 to 100 kbps. Since the Manchester code is specified by the upper mentioned standard, the noise effect on it is investigated. Even if the Manchester code has numerous advantages, it has the disadvantage of an increased bandwidth requirement. On the other hand, the Miller code [19] clearly outperforms the Manchester code in terms of bandwidth efficiency, making it appropriate for Multiple Input Multiple Output (MIMO) applications as demonstrated in [20]. For this reason, the noise effect on the Miller code is also analyzed.

III. SIMULATION RESULTS

In order to determine the noise influence on the pulse width, several simulations were performed. The simulations involve the coding of random messages using the Manchester and the Miller codes. The messages are transmitted at a modulation frequency of 15 kHz at different SNR levels. The simulated receiver architecture (Fig. 2) assumes the use of a 12 bits ADC module. In order to be able to insure decent signal processing, the sampling frequency is 100 times the data frequency, leading to 1.5 MHz. The filtering is performed by two low-pass Butterworth 2nd order cascading filters separated by a partial signal reconstruction block.

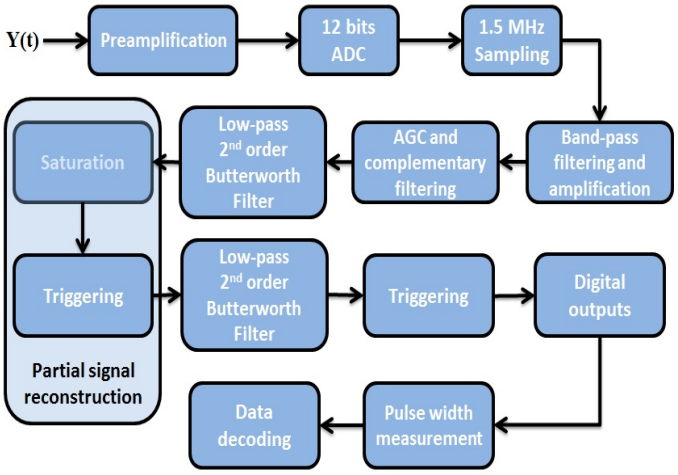

Fig. 2. VLC receiver architecture model.

The usage of the Butterworth filtering [21] was considered as it does not introduce ripples to the signal. After filtering, the signal passes through a two level triggering block that outputs the replication of the emitted signal. The pulse widths of the reconstructed messages are measured and analysed in order to determine the noise influence. We mention here that the simulated set up was a simplified one. More complex signal processing techniques, higher order filtering or adaptive threshold algorithms can minimize the effect of the tested noise levels. However, as the SNR continues to depreciate the effects on the pulse widths are similar, meaning that the pulse distortions still occur.

For the purpose of these tests, random messages were coded using Manchester and Miller code. The main parameter of the signal containing the encoded data is the width of the elementary moments of the digital bits. For the Manchester code, there are only two symbols (positive edge and negative edge) and it leads statistically to only two combinations of widths: either one elementary bit width, or twice the elementary bit width. On the other hand, in the case of the Miller code, the memory effect leads to three possible combinations: either one momentary width, one and a half or twice the width [22]. The possible pulse widths variations for the two codes are presented in Fig. 3.

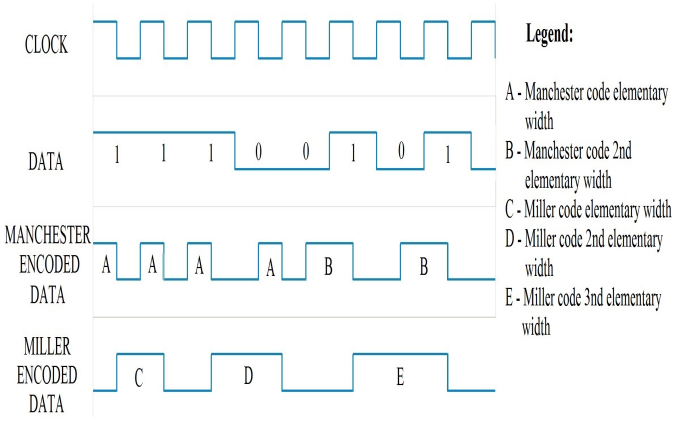

Fig. 3. Illustration of the possible pulse widths in Manchester and in Miller code.

At the receiver side, after passing through the stages mentioned above, the values of 10^5 pulses from each of the pulse width types were saved and analysed for both codes. It needs to be clarified that for both Manchester and Miller codes, a coded frame does not contain an equal numbers of pulses from the two respectively the three pulse widths types. The number of pulses from each category depends on each message. From this reason the data gathering process continued until the 10^5 number of pulses for each of the pulse width types was achieved. The results concerning the noise effects on the pulse width are plotted in Fig. 4 for three SNR levels and both the Manchester and Miller codes. It can be noticed that as the SNR decreases, the pulse widths are more affected by distortion. Also, the number of pulses that are affected significantly increases. The pulse distortions represent a major issue affecting the communication performances since the decoding is performed based on the identification of the rising and falling edges and on the pulse width measurement. In this case it is obvious that pulse distortions above certain tolerances will cause decoding errors.

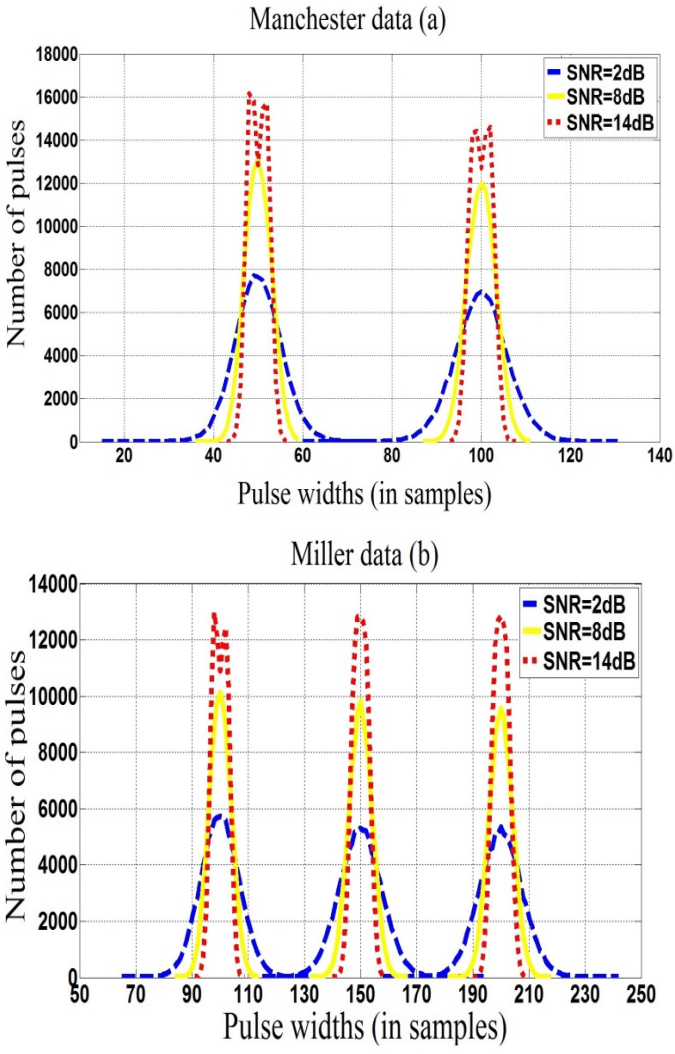

Fig. 4. Histograms of received pulse widths for both Manchester and Miller configurations; Simulation results; a) Manchester case b) Miller case.

It can be observed that in the case of the Miller code, the distortion percentage is not as high as for the Manchester code. This is even more obvious in Fig.5 where is presented the percentage of pulses that have a width distortion greater than 5%. The Miller code presents lower distortions because it has a longer pulse and thus uses a greater number of samples per pulse for the filtering process.

The pulse width distortions do not pose a significant problem as long as they do not affect the pulse width to such a degree that it introduces uncertainty in the data decoding. Fig. 6 presents the number of pulses that were affected by distortion in a degree that produces decoding errors for the two codes. It can be observed that in the case of the Miller code, the Pulse Error Rate (PER) is significantly higher than the PER of the Manchester code. Due to its nature, the Miller code is more sensitive to pulse length variation. In its case, pulse width variations of 12.5 to 25% create uncertainty in decoding. In the case of the Manchester code, the distortion percentage that creates uncertainty is double. However, a Miller pulse has a greater length and therefore it carries more data, making the Bit Error Ratio (BER) similar to the one of the Manchester code.

Another interesting finding revealed during the tests is related to the nature of the errors. In the case of the Manchester code more than 75% of the errors are caused by missing edges, due to insufficient filtering. Basically, the signal quality was low and proper signal reconstruction was not achieved because of noise and the limited number of samples per pulse used in filtering. On the other hand, in the case of the Miller code, the errors are caused by the limited tolerances. For example, in the case of a double length Miller pulse, a -12.5% distortion creates uncertainty in decoding being confused with a middle size pulse.

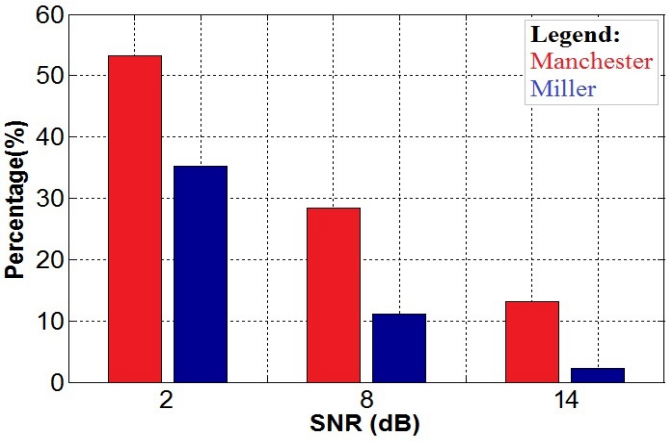

Fig. 5. Percentage of pulses that are affected by a distortion greater than 5%.

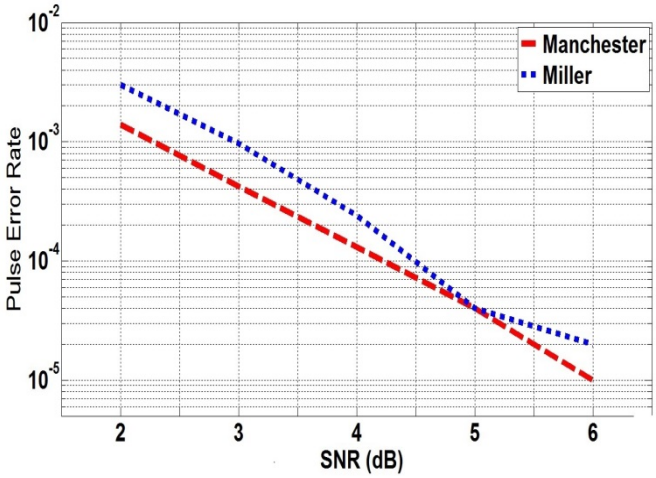

Fig. 6. Pulse error ratio for Manchester and for Miller codes

The purpose of the next tests was to determine the BER performances of the two codes. Short messages of 4 ASCII characters (4*8 useful bits) were encoded using the two codes. The structure of the frame also contains several synchronization bits, a start and a stop bit, as presented in Fig. 7.

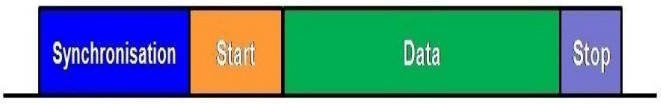

Fig. 7. Structure of the data frame.

At the receiver side, the messages were decoded using the architecture from Fig. 2, for different SNR levels. The BER results for these tests are represented in Fig. 8. It can be observed that at low SNR levels, the Miller and the Manchester codes show similar results, with a 10% better BER in the case of the Miller code. However, as the SNR improves (4 – 5 dB), the BER performances seem to get better in the case of the Manchester code, and tend to get even considering a 10^{-7} level.

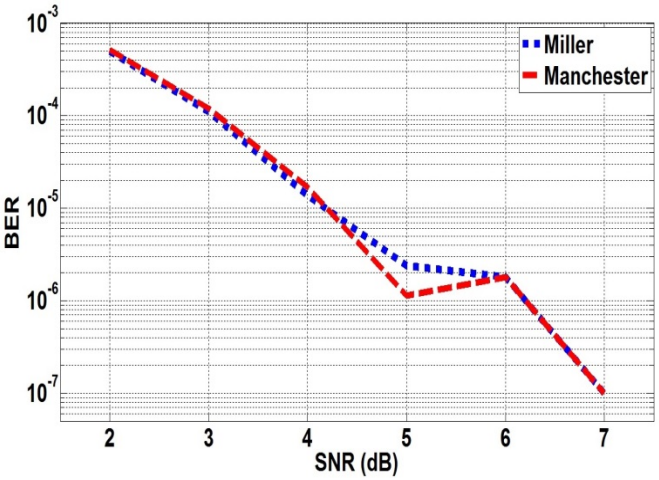

Fig. 8. Bit error ratio for Manchester and for Miller codes

This behavior can once again be attributed to the nature of the two codes. At low SNR levels, the improved filtering performances of the Miller code give it a slight advantage over the Manchester code. As the SNR gets higher, the Manchester coded signal is decently filtered while the Miller coded signal is affected by the stricter tolerance limit. These results can be improved by using higher level filtering, improved pulse reconstruction algorithms or other signal processing techniques, which will mitigate the noise effects on the pulse width to lower SNR levels.

The fact that the Manchester and the Miller code exhibit similar BER performances was also experimentally confirmed in [23] for distances of up to 50 meters.

IV. CONCLUSIONS

This paper presented an analysis over the noise effect on the VLC signal pulse width for the case of digital signal processing. We investigated both the Manchester and Miller codes providing simulation results and we proposed a VLC receiver architecture. The results showed that as the SNR decreased, the pulse widths were more and more affected by distortion, leading to decoding errors. It was observed that due to its nature, the Miller coded signal was better filtered, but it was affected by stricter tolerances limit, which was the main cause for errors. In the case of the Manchester code, the digital filtering was less effective but it has recovered due to its higher tolerance to pulse width variations. Under these circumstances, the two codes had similar BER results.

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.

As future work, we plan to improve the proposed receiver architecture, to implement it on a hardware DSP system and to test it in real conditions.

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**The 12th International Conference on
Development and Application Systems
DAS 2014**

**May 15-17, 2014
Suceava - Romania**

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Paper ID: 39
Sensors Network Based on Mobile Robots
Victor ABABII, Viorica SUDACEVSCHI, Marin PODUBNII, Irina COJUHARI
Technical University of Moldova, Chişinău, Republic of Moldova

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Using dual priority scheduling to improve the resource utilization in the nMPRA microcontrollers
Nicoleta Cristina GAITAN, Lucian ANDRIES
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Paper ID: 44
Introducing aceMote: an energy efficient 32 bit mote
Andrei STAN, Nicolae BOTEZATU
Gheorghe Asachi Technical University of Iaşi, Romania

Paper ID: 48
Evaluation of the noise effects on Visible Light Communications using Manchester and Miller coding
Alin-Mihai CAILEAN[1,2], Barthelemy CAGNEAU[2], Luc CHASSAGNE[2], Valentin POPA[1], Mihai DIMIAN[1]
[1] University of Versailles Saint-Quentin, Vélizy, France
[2] Ştefan cel Mare University of Suceava, Romania

Paper ID: 53
Implementation and Performance Analysis of Zero Forcing MIMO Detection Algorithm
Vakulabharanam RAMAKRISHNA[1], Tipparti Anil KUMAR[2]
[1] Department of Electronics & Communication Engineering, JNTUH, Hyderabad, India
[2] Department of Electronics & Communication Engineering, SR Engineering College, Warangal, India

Paper ID: 58
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Lucian-Nicolae COJOCARIU, Valentin POPA
Ştefan cel Mare University of Suceava, Romania

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