Proposed Model of Street Lighting System based on OFDM Operations for Smart Lighting

Mehdi Laraki and Aawatif Hayar
Smart City Team, RITM Laboratory, CED ENSEM, GREENTIC, Casablanca, Morocco

Keywords: Street Lighting System, Voltage Command, OFDM Techniques, Smart Lighting, Smart City.

Abstract: Abandoned for a very long time, because of the complexity of their Multi-Carrier techniques (Multi Carrier Modulation, MCM or Orthogonal Frequency Division Multiplexing OFDM), nowadays, the OFDM has become the strategic choice of several systems modern digital products. Its simplicity and flexibility, as well as the transmission, make them particularly interesting for communication systems. Inspired from Telecommunications field, especially from the OFDM Techniques, the aim of this paper, is to propose a model of street lighting system based on OFDM operations, this technique is used here control and to switch On/Off the street lamps and to launch a proposed waveform of voltage command of lighting when pedestrian or vehicle detections are occurred, even in cases of multi detections in streets or in other words branches of street lamps. This proposed model will allow us to illuminate intelligently by using a new strategy of voltage command of lighting and to reduce considerably the rate of power consumption during the lighting for smart lighting and so, contributing on having a smart city.

1 INTRODUCTION

The idea of multicarrier transmission is very simple, in fact, the source of bits stream is divided into several sub-streams. The transmission sub streams use orthogonal signals, which can be simply recovered in reception. Nowadays, the Multi Carrier Modulation MCM can be totally realized in digital by using discrete Fourier transform (DFT) algorithms, which are at the origin actually of the OFDM Orthogonal Frequency Division Multiplexing. MCM techniques are not new, already used for military High Frequency (HF) applications in the late 1950s, in the 1990s, they are found in several cable and communication systems: DAB and DVB in Europe, ADSL and more recently in WLAN wireless LAN systems. The MCM techniques were discovered in 1950, but unfortunately the complexity of the modulators / demodulators in perfect orthogonality for each subchannel rendered the method uninteresting. It will take about 20 years for the processing circuits to be able to perform discrete Fourier transforms efficiently and at low cost, providing us finaly the OFDM Modulation technique. The use of DFT made MCM techniques simple to generate and especially to demodulate. Currently in telecommunication systems, the 4G or LTE is based on the OFDM modulation technique with a data transmission realised using orthogonal signals, and simply recovered in reception, the following figure.1 illustrates the evolution of modulation techniques, and recently we use OFDM Modulation beyond 3G (A. Bahai, 2004).

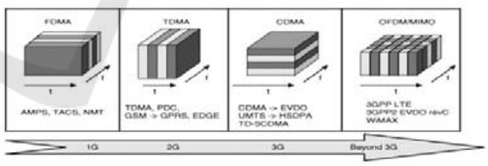

Figure 1: Using of OFDM modulation beyond 3G in data transmission.

Inspired from the OFDM Techniques introduced in the Section II of this article, we will propose to you in the section III, a new model of street lighting system based on OFDM operations, this technique will allow us to select the desired street lamp and to launch a proposed waveform of lighting in function of the sensors concerned by the detections, to illuminate intelligently and reducing considerably the power consumption during the lighting by using a new strategy of lighting command and lighting voltage control, and so, having a smart lighting and contributing on having a smart city.

Laraki, M. and HAYAR, A.
Proposed Model of Street Lighting System based on OFDM Operations for Smart Lighting.
DOI: 10.5220/0006350502870292
In *Proceedings of the 6th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2017)*, pages 287-292
ISBN: 978-989-758-241-7

2 OFDM TECHNIQUES

2.1 FFT and IFFT Operations in OFDM

In OFDM, the data is divided into blocks of size N (N symbols). Each block is called an "OFDM symbol», Figure 2.

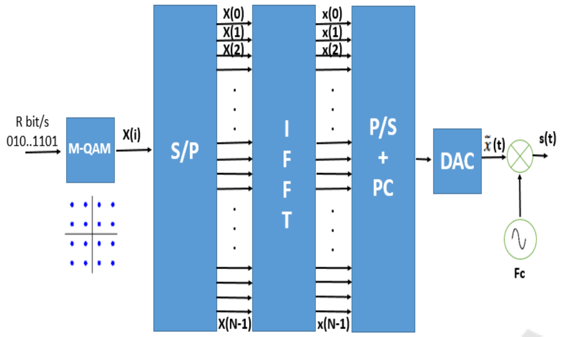

Figure 2: OFDM Modulator transmission.

Let's take x(n) ; n = (0, 1, 2, 3,. . . , N -1) a sequence of complex samples in discrete time, we define the discrete Fourier transform function DFT, Inverse Fourier transform as the following (A. Bahai,2004)(Yong Soo Cho,2010).

$$\mathrm{DFT}\{x(n)\} = X(i) = \frac{1}{\sqrt{N)}} \cdot \sum_{n=0}^{N-1} x(n) e^{-j2\pi ni/N} \quad (1)$$

$$\mathrm{IDFT}\{X(i)\} = x(n) = \frac{1}{\sqrt{N)}} \cdot \sum_{i=0}^{N-1} X(i) e^{j2\pi ni/N} \quad (2)$$

$$1 \le i \le N-1 \quad ; \quad 1 \le n \le N-1$$

s(t) represents the transmitted signal, each complex symbol X(i) is modulated by the IFFT on the frequency f(i) as illustrated in the figure.3.

$$\begin{cases} f(i) = e^{-\frac{j2\pi ni}{N}} \\ 1 \le i \le N-1 \\ \text{Couple } (f(i); f(j)) \text{ are Orthogonal} \quad \text{for } i \ne j \end{cases} \quad (3)$$

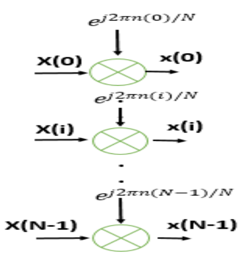

Figure 3: IFFT Orthogonal Frequency Multiplication.

2.2 OFDM Frequency Waveform

By using the OFDM, the available frequency band is divided into several orthogonal sub channels, carrying independent symbols. (Yong Soo Cho, 2010; Tzi-Dar Chiueh, 2012).In time domain we note:

$$s_n(t) = \begin{cases} e^{j2\pi n\Delta ft} & \text{if } Tg \le t \le Ts \\ 0 & \text{if } Tg > t \text{ and } t > Ts \end{cases} \quad (4)$$

In frequency domain we note:

$$S_n(f) = T.\frac{\mathrm{Sin}(\pi.T.(f - n\Delta f)}{\pi.T.(f - n\Delta f)} \quad (5)$$

$$T = Ts + Tg\,; \;\; \Delta f = 1/Ts \quad (6)$$

Where:

Ts: Useful OFDM symbol duration or symbol time.
Tg: Guard interval duration.
T: Total OFDM Symbol duration.
S_n: The n th Subcarrier.
Δf: Frequency spacing between sub carriers.

The base band signals is written in time domain respectively in frequency domain as the following:

$$x(t) = \sum_{n=0}^{N-1} X_n . g_n(t) \quad (7)$$

$$X(f) = T.\sum_{n=0}^{N-1} X_n . \frac{\mathrm{Sin}(\pi.T.(f - n\Delta f)}{\pi.T.(f - n\Delta f)} \quad (8)$$

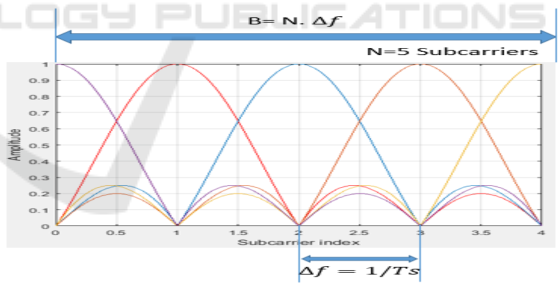

Figure 4: Realization of N subcarriers orthogonality N=5.

The figure.4 represents a Matlab simulation of 5 subcarriers with a fix frequency spacing between subcarriers Δf. The OFDM symbol in the figure 5 corresponds to a composite signal of N=5 symbols in a parallel form, which has a duration of Ts.

In the following section (Section III) we will propose you a new street lighting system based on the OFDM Operations and OFDM signal spectrum as introduced and explained in this section (Section II).

3 PROPOSED STREET LIGHTING SYSTEM BASED ON OFDM OPERATIONS

3.1 Street Lighting Norms and Design

We measure the intensity distribution of the road light by using the C-γ photometric convention. Indeed, in the C-γ photometry, C represents the angle on the road surface plane, γ represents the angle between vertical axis of the street lamp and lumen throwing direction. Intensity I is calculated from the equation of the Illuminance as the following: (Owen Ransen, 2014; Electrical4u, 2017)

$$\mathrm{Ep} = \frac{\mathrm{I}.\cos^2(\gamma)}{\mathrm{h}^2} \tag{9}$$

EP: The Illuminance at point P on the road.
h: The vertical height from the point P to the luminaire.

After calculation of the intensity, we put all the intensity values making a C-ɣ table as per their angular position. In this table C' is the position of maximum intensity on the table.

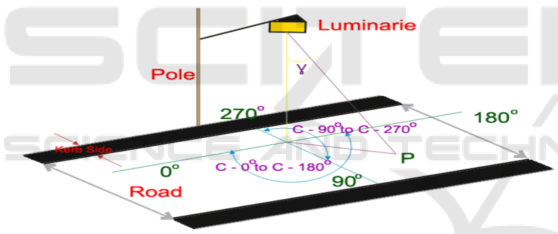

Figure 5: Three basic planes of intensity considered on the road surface with one Street lamp.

Three basic planes of intensity are considered on the road surface with one Street lamp as shown in Figure 5: (Owen Ransen, 2014; Electrical4u, 2017)

- Plane1: C-0^0 to C-180^0 along the road.
- Plane2: C-90^0 to C-270^0 across the road.
- Plane3: Principle Plane, through the point of maximum intensity of the light, i.e. C' to C' + 180^0

C' is obtained by preparing intensity distribution chart of the street lamp on the road. Where intensity will meet at maximum value this is the degree value of C'. Two indices are related to the road light luminaire, the first one is the Spread angle, representing the angle of the luminaire to direct the luminous flux across the road, and the second is the Throw angle, representing the angle of the luminaire to direct the luminous flux along the road, the figure 6 illustrates these two angle: (Owen Ransen, 2014; Electrical4u, 2017).

$$\begin{cases} \gamma_{\max} < 60^0 & \text{Short throw angle} \\ \gamma_{\max} > 70^0 & \text{Long throw angle} \\ 60^0 < \gamma_{\max} < 70^0 & \text{Intermediate throw angle} \end{cases} \tag{10}$$

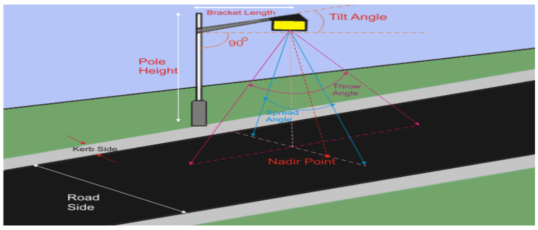

Figure 6: Spread and Throw angles representation.

3.2 Proposed Street Lighting System based on OFDM Operations

Smart lighting means providing only the necessary and sufficient light to see and be seen and to ensure the safety of people and road users in general according to their activity and the specificities of the places, indeed when the lighting equipment is still in good functional condition, and for a low investment, it's possible to realize considerable energy savings without necessarily replacing the street lamps by installing motion sensors and using intelligent strategies of lighting command and lighting voltage control as we will explain in the following chapters of this section. Inspired from the OFDM Techniques introduced previously in the chapter II, we propose you in the following chapters of this paper, a new model of street lighting system based on OFDM operations, this model will allow us to select the desired street lamp and to launch a proposed waveform of lighting in function of the sensors concerned by the detections. This proposed model will allow us to illuminate streets intelligently by using a new strategy of voltage command of lighting and to reduce considerably the power consumption during the lighting. Let's consider now a series of N sensors s(i) , practically, sensors are fixed to their respective street lamps, the sensors will allow us to inform if there is detections or not (detections of pedestrians, vehicles, bikes …), s(i) is defined as the following :

$$\mathrm{s(i)} = [\mathrm{s(1)\ s(2)\ s(3)\ \ldots\ s(N\text{-}1)\ s(N)}] \tag{11}$$

$$\begin{cases} \mathrm{s(i)} = 1 & \text{if detection} \\ \mathrm{s(i)} = 0 & \text{else} \end{cases} \qquad 1 \le i \le N \tag{12}$$

Now, we consider S a binary stream sequence of detections of size N and $A_{(i,j)}$ its associated square matrix of size N defined as the following:

$$\mathrm{S} = \mathrm{s(i)} = [\mathrm{s(1)\ s(2)\ s(3)\ \ldots\ s(N\text{-}1)\ s(N)}] \tag{13}$$

$$A_{(i,j)} = \begin{bmatrix} s(1) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & s(N) \end{bmatrix} \quad (14)$$

$$1 \le i;j \le N$$

$$\begin{cases} A_{i,j} = s(i) & \text{For } i = j \\ A_{i,j} = 0 & \text{else} \end{cases} \quad (15)$$

The A matrix will help us modeling the serial to parallel converter and to plot easily overlapping subcarrier spectrum. Now, we operates an Invert Fast Fourier Transform IFFT along each column of the matrix A, each column represents a subcarrier, the IFFT is defined as the following:

$$D_{(i,j)} = \mathrm{IFFT}\,[A_{(i,j)}] \quad (16)$$

$$D_{i,k} = \frac{1}{N}.\sum_{k=1}^{N} C_{i,k}.\,e^{j2\pi ki/N} \quad (17)$$

$$C_k = [\,C_{1,k}\,C_{2,k}\,\ldots\ldots C_{i,k}\,\ldots\ldots C_{N,k}\,]^T \quad (18)$$

$$D_k = [\,D_{1,k}\,D_{2,k}\,\ldots\ldots D_{i,k}\,\ldots\ldots D_{N,k}\,]^T$$

$$1 \le i \le N$$

D_k: Represents the m th column of the matrix D.
C_k : Represents the k th column of the matrix A.
N: Represents the number of street lamps in the street branch or road and also the subcarriers generated.

We propose to do a Fast Fourier Transformation FFT with a resolution multiplied by N, so we'll have the following:

$$F_{(i,j)} = \mathrm{FFT}\,[D_{(i,j)}] \quad (19)$$

The figure 7 illustrates our proposed model of street lighting system based on OFDM operations.

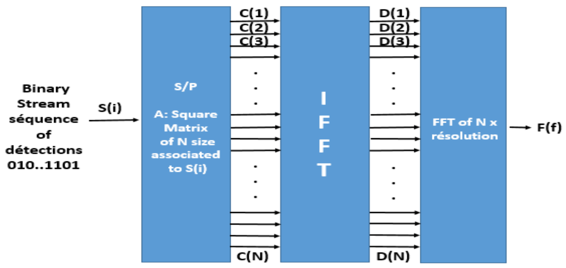

Figure 7: The proposed model of street lighting system.

The following figures illustrate the subcarriers spectrum in frequency domain generated in different binary sequences of detections S, we'll take into account the following:

- Simulation in figure 8: S1 = [0 0 1 0 0]
- Simulation in figure 9: S2 = [0 1 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 1 0]

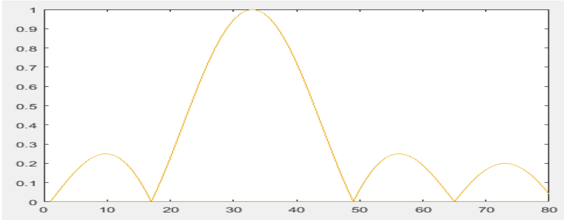

Figure 8: Lighting waveform represented by subcarriers spectrum generated for the binary sequence of detections in a street branch of N street lamps (N=5; FFT of 16xN resolution).

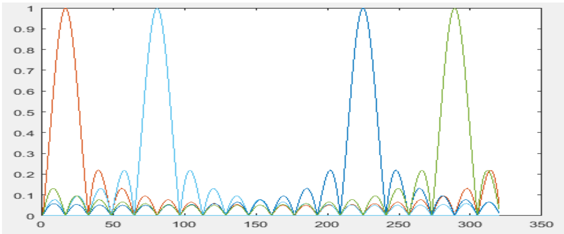

Figure 9: Lighting waveform represented by subcarriers spectrum generated for the binary sequence of detections in a street branch of N street lamps (N=20; FFT of 16xN resolution).

Indeed, and according to the results obtained in the figures (Figures 8,9) in each detection detected by a motion sensor s(i), a Cardinal Sine Signal is launched in the i th street lamp concerned by the detection. The model is based on tracing the signal generated in frequency domain as illustrated in figures 8,9, to the time and spatial domain in order to generate the waveform of voltage command of lighting as illustrated in the figure 10.

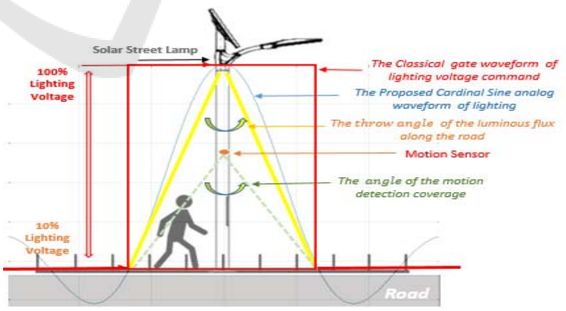

Figure 10: Waveforms of lighting represented in spatial domain in the i th Street Lamp when the i th motion sensor is detected.

Indeed, by using the classical gate waveform of voltage command we obtain a uniform spatial lighting intensity as illustrated in the figure 11, by using our proposed lighting model, cardinal sine waveform of lighting we will obtain a degraded lighting with an increasing intensity in the direction of the street lamp position figure 12.

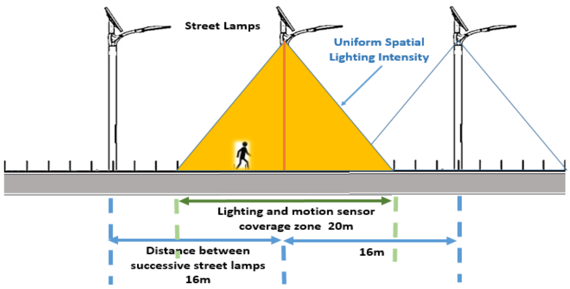

Figure 11: Uniform Spatial lighting intensity by using classical gate waveform of voltage command of lighting.

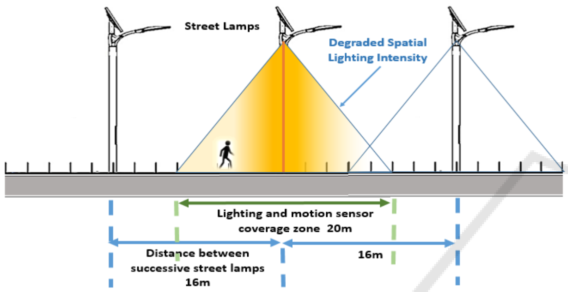

Figure 12: Degraded Spatial lighting intensity by using proposed cardinal sine waveform of lighting.

We can notice from the figures, figure 11, 12 that unlike the classic model "gate waveform of voltage control of lighting", the proposed model "Cardinal sine waveform of lighting" does not keep the lighting voltage to the maximum, which will allow us to optimize energy consumed at each detection during the lighting. For voltage command, we propose to sample the cardinal sine analog lighting waveform, sampling can be modelled by a pulse train as the following:

$$\delta = \sum (t - kTs) \tag{20}$$

Taking into account the following:

-The power of lighting is fixed in the interval P = [10%; 100%].

-The average speed of pedestrians is about v = 1m/s.

-The distance between two successive street lamps is d=20m.

The Cardinal Sine analog lighting waveform will evolve in a interval of time τ defined as below:

$$\tau = \frac{d}{v} = \frac{20\text{ m}}{1\text{m/s}} = 20\text{s} \tag{21}$$

The sampling of the proposed lighting waveform is expressed as below:

$$Ws(t) = Sinc(0.25t).\sum_{-\infty}^{\infty}(t - kTs) \tag{22}$$

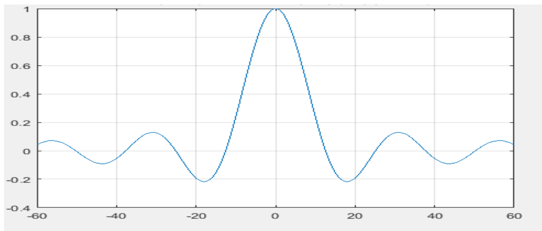

Figure 13: Time domain representation of Cardinal Sine analog lighting waveform evolving in a interval time $of\ 20s$.

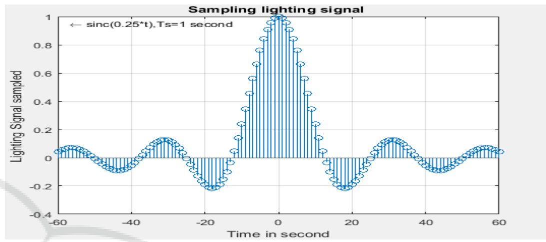

Figure 14: Time domain representation of Cardinal Sine waveform of lighting discretized evolving in an interval of time $\tau = 20s$.

To insure the diming of lighting, we connect dimmers to a street lamps in order to command lighting by varying the voltage command, the correspondence between intensity of lighting and the voltage command is represented in the figure 15.(Smarthomatic,2016).

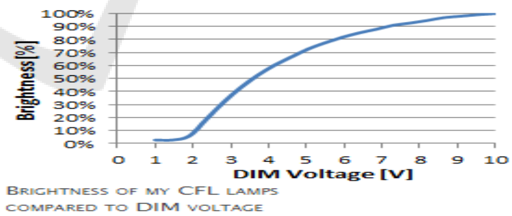

Figure 15: Curve of the correspondence between intensity of lighting and the voltage command of the dimmer.

As we notice from the figure 15, the curve represents an aspect of logarithmic function, so we can write the following:

$$I = \ln(V) \tag{23}$$

Where I representing the brightness or the intensity of lighting, and V the voltage applied by the dimmer, so we can write the following:

$$V = e^{I} = e^{Sinc(0.25t)} \tag{24}$$

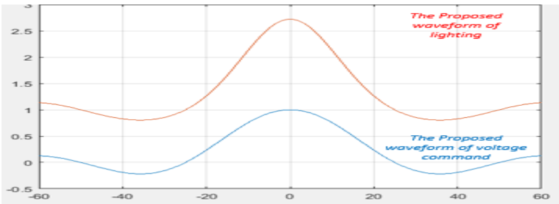

Figure 16: Time domain representation of the proposed waveform of lighting and the proposed waveform of voltage command.

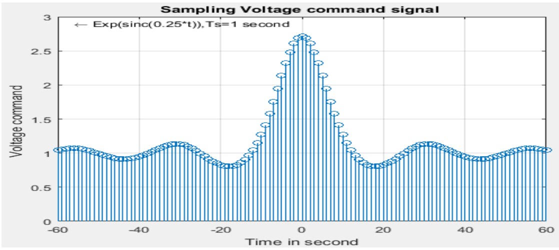

Figure 17: Time domain representation of the proposed voltage command of lighting (discretized) the dimmer should apply to illuminate with the proposed lighting model.

3.3 Energy Saving

We propose in this chapter to make an analysis and comparison between the classical gate waveform of voltage command and our proposed cardinal sine waveform of voltage command .The aim, is to determine which of these models save the most energy during the lighting. With a temporization lighting time of τ = 20s and a power of lighting of (P=13 W, 1500 Lumens) evolving between 100% and 10% in standby mode. We can calculate the energy consumption:

$$E_1 = \int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} P.\prod(x)\,dx \tag{25}$$

$$= P.\tau = 13W.90\%.20s$$

$$= 234\ \text{Joules}$$

$$E_2 = \int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} P.\mathrm{Sinc}(0.25x)\,dx \tag{26}$$

$$\simeq 13W.11{,}6 \simeq 150{,}8\ \text{Joules}$$

Where E_1 is the energy consumption of the classical model and E_2 the energy consumption of our proposed model, and $\prod(\mathbf{x})$ the gate function defined as the following:

$$\prod(t) = \begin{cases} 1\,; & -\frac{\tau}{2} \le t \le \frac{\tau}{2} \\ 0{,}1\,; & t < -\frac{\tau}{2} \text{ and } t > \frac{\tau}{2} \end{cases} \tag{27}$$

Table 1: Table summarizing the energy consumption analysis between the classical lighting model and the proposed lighting model.

	RATE OF POWER ENERGY CONSUMPTION
CLASSICAL LIGHTING MODEL	100%
PROPOSED CARDINAL SINE LIGHTING MODEL	64.5%

We notice that the proposed cardinal sine model of voltage command save energy during the lighting comparing to the classical model with a optimization gain of 35,5 %.

4 CONCLUSION

We proposed in this paper a model of street lighting systems based on OFDM operations, this technique is useful to switch On/Off the street lamp and to launch a proposed waveform of voltage command of lighting when pedestrian or vehicle detections are occurred along the roads. This proposed model will allow us to illuminate roads intelligently by using a new strategy of voltage command of lighting and to reduce considerably the power consumption during the lighting, and so illuminating smartly. A complete study of this proposed strategy and saving energy, will be the subject of our future works and publications.

REFERENCES

A. Bahai, B. R. Saltzberg, and M. Ergen, 2004. The book, Multi-Carrier Digital Communications: Theory and Applications of OFDM, 2nd ed., New York: Springer Verlag, 2004.

Yong Soo Cho, Jaekwon Kim, Won Young Yang, Chung G. Kang, 2010.The book, Mimo-OFDM Wireless Communications with Matlab, IEEE 2010.

Owen Ransen, 2014.The book, Candelas, Lumens and Lux.

Electrical4u, 2017. Road lighting design Website, ONLINE ELECTRICAL ENGINEERING STUDY SITE, http://www.electrical4u.com/road-lighting-design/.

Tzi-Dar Chiueh, Pei-Yun Tsai, I-Wei Lai, 2012. The Book, Baseband Receiver Design for Wireless MIMO-OFDM Communications 2nd Edition.

Smarthomatic, a secure and extendable Open Source home automation systemcopyright2013.. 2016, https://www.smarthomatic.org/devices/dimmer.html.