Machine to Machine Based on Visible Light Communication for IoTs

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***Abstract*—Machine-to-machine (M2M) visible light communication (VLC) is a communication architecture that makes it possible for heterogeneous devices to interact without human intervention using visible light modulated at certain frequency to enable communication. M2M VLC based is one of the feasible applications of internet of things (IoTs). This paper proposed a machine type communication (MTC) for M2M VLC based with an incorporation of energy harvesting system using a power transfer unit (PTU) with a centralized VLC access point (AP) with a probabilistic model, where an investigation is performed to show the signal to noise ratio (SNR) distribution with a semi angle at half power of a chosen link. This is done by varying some parameters.**

This model considers the channel analysis and light emitting diodes (LEDs) are place at the ceiling showing how bit rate can be effected for VLC AP with equal separation for a mobile devices or users. Such network aims at interconnecting billions of devices while investing the throughput performance of the M2M VLC based where a cluster of energy harvesting devices communicating with a VLC AP. This paper aims at proposing a design at the physical layer using various modulation schemes, demodulation, synchronization, error correction and so forth to ensure optimal communication can be made to the internet. Both LEDs-based analog transceiver devices and photo-detectors are exploited. The method is implemented in simulation and considering the performance and flexibility of the system.

***Index Terms*—Visible light communication, machine-to-machine, machine type communication, optical wireless communication, internet of things.**

I. Introduction

The exponential increase in the number of devices that require internet services, especially with the machine-to-machine (M2M) and the internet of things (IoTs) nowadays, has an impediment of extinct electromagnetic spectrum. Alternative communication technologies that are more efficient and effective with less interference and wild spectrum are crucial to maintain this advancements. Radio frequency (RF) wireless technologies such as wireless fidelity (Wi-Fi), long term evolution advanced, Bluetooth, Zigbee, just to mention only a few, have limited availability of frequency spectrum and power usage. On the other hand, visible light communication (VLC) with a very wide spectrum ranging up to $\approx$ 300 THz is readily available and yet unlicensed. In VLC, light emitting diodes (LEDs) are used to provide a light signal which is modulated at high speed to carry information, in addition to it lower power consumption. This VLC technology has many advantages such as not having electromagnetic interference, harmless to human. As such, it can be exploited in applications that are sensitive to radio frequency (RF) interference such as hospital, aircraft and other environments. As an M2M communication platform, VLC is incorporated as to form an IoTs communication, to sustain applications such as smart home, smart office, remote monitoring, vehicle-to-vehicle communication, digital signage, wireless sensor networks, just to name a few [1]. The objective of this paper involves deducing the performance of the SNR using the system geometry, by investigating the effect of increasing the power and the field of view (FOV). With the advent of IoTs connecting thousands of devices, such systems are very much applicable in IoTs.

The remainder of the paper is organized as follows. In section II, we provide a comprehensive literature review and relevant research work. Section III gives us an idea of the system Model and description. Section IV describes the preliminary analysis. Section V discusses the simulations and the probable results of the proposed M2M based on VLC technology, and section VI concludes the paper with some future directives and its implementation in IoTs.

II. Literature Review

The importance and efficiency of sustainable energy resources for (IoT) devices, due to high rate of energy consumption is a major handicap in optical wireless communication (OWC). With some very crucial and helpful schemes of energy harvesting in RF which include the wireless power transfer (WPT) [2] and simultaneously information and power transfer, are use in RF energy harvesting technology, with the introduction of IoT, the spectrum has become insufficient. VLC as a promising savior for the extinction of RF electromagnetic spectrum has challenges of providing an effective quality of service where it will have to consider energy of the devices. It is quite challenging to keep charging or replenish the batteries of such devices, most especially in harsh environment. Energy harvesting (EH) technology is an approach to sustain the lifespan of the network [3].

Some limiting factors of VLC links include the beam width of the transmitter, the receiver orientation, and the field of

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View (FOV) of the receiver. If the above setbacks are properly managed, an expected high signal to noise ratio (SNR) and high data rate can be achieved. In case of mobile devices like vehicle-to-vehicle communication, a single beam VLC AP is not reliable to provide the user with connectivity at the VLC AP. When there is a need for handover (a situation in where the user moves from the one cell containing a VLC AP to another cell with a different VLC AP).

It was introduced in [4], that on-off keying (OOK) modulation technique achieved a lower bit error rate (BER). Researchers in [5] proposed that by tilting atto-cells towards the corner of the room, the SNR increases with an increase in received power. Researcher in [6], [7], provided an approximation for BER expression. Again, in [8] the authors proposed a system with improve SNR while maintaining the threshold illumination levels with 16 atto-cells configured to achieve a high SNR and received power. Researchers in [9], Proposed a handover delay and found the numerical overlap between cells needed to achieves an intended handover. Researchers in [10], proposed and investigated the base station support system for indoor VLC that satisfy condition given by the users. References [11], exploited an approach to manage handover that provide cooperation and coordination between VLC terminals in an overlapping and non-overlapping light sources.

A. Visible light communication

In order to be able to sustain the high influx thirst for high data and better quality of services. Researchers have continuously carried research on VLC technology. It is known that most, if not all the VLC technologies are borrowed and adopted from it's counterpart RF and other OWC technologies. Even though, VLC is a short range transmission, relay-assisted schemes have been adopted to mitigate fading, and it's short transmission range nature [12]. In order to maintain a long range of transmission, VLC systems can be cascaded with backbone networks such as laser, power line communication, fiber optics just to mention a few [13], [14], [15], [16].

VLC technology is part of the OWC. Therefore properties of OWC are applicable to VLC. VLC is consisted of three main parts, transmitter, channel and receiver and often characterized by additive white Gaussian noise (AWGN) [17]. Although, visible light spectrum is not fully regulated, and to regulate the VLC technology, the institute Electrical and Electrical and Engineers working group (IEEE) 802.15.7, proposes schemes and techniques to guide its communication [18]

B. Machine-to-machine communication

M2M communication refers to the heterogeneous interaction of devices connected in a network without the invention of human. Recently, RF communication were intended for human-human (H2H) communication, all having different properties from the M2M communication. Similarly, VLC was also oriented towards a H2H communication, as there is a need for adapting VLC to support M2M.

Over the past decades, the growth in wireless communication has made researchers to provide infrastructure where M2M communication could be feasible. By this, there have been a significant development in software that can allow devices to autonomously operate coupled with sensors and actuators which are used to collect information for M2M systems [19]. To interconnect these smart devices while ensuring a high date rate, short range communication technologies, it is important to incorporate M2M components in a VLC system. To facilitate M2M communications, the prominent and appealing solution is the VLC system owing to it readily available spectrum. This happen when machine-type-communication devices are connected to VLC access points. Looking at the exponential increase in the number of MTC devices [20], there is an urgent need for integrating M2M communication in VLC systems.

C. Illumination Analysis

The visible light section of the electromagnetic spectrum ranges from 380 nm to 770 nm, and the power of the light can be calculated from the energy it radiates using the Plank's equation of quantum theory. It is important to note here that VLC and illumination environments like smart homes, offices, hospitals have a constant illumination as a result only direct line-of-sights are taken into considerations.

D. Machine-to-machine visible light communication channel

In M2M communication, many devices are autonomously connected to each other [1]. In this regard, integrating this technology in VLC light communication comes in to play as a results of an overcrowded electromagnetic spectrum and limited bandwidth. In VLC technology, this limitation are well taken care of. In this paper, we propose a system where each device is containing a photodetector at the receiver and LED and transmitter. Also, for the case of smart homes, a proposed solar panel is attached at the top of the building where all the rays of light are directed and relayed into the indoors of the building.

The ultimate and unique proposal of the paper is to design and analyze the VLC AP for a chosen link in a M2M communication system. Here we proposed a channel analysis with SNR distribution for semi angle at half power and the FOV for an indoor scenario.

III. System Model and Description

In M2M VLC based systems, the channel is the space from the transmitter antenna (LEDs) to the receiver antenna (PD). The channel is characterized by its ability to transmit the carrier signals. It important to know many factors influence its transmission such as attenuation, interference, and noise. In an M2M VLC based system, the channel could be characterized as single or multiple channels. Single channels are such that only one LED and one PD are utilized. Multiple channels is when there exist multi-colored LEDs. In an indoor environment, such as office, smart homes, just to mention a few, both line-of-sight (LoS) and non-line-of-sight (NLoS)

are considered. For outdoor environment such as vehicle-to-vehicle communication, we consider replacing LEDs with laser light to maintain a considerable threshold transmission distance. Therefore, only LoS is considered. This is because the power due to the NLoS is negligible when compared with the power from LoS part.
Again, our goal in this paper is to propose new models of M2M VLC based systems and predict the performance under some scenarios. The approach here is based on exploiting SNR coupled with the channel analysis.

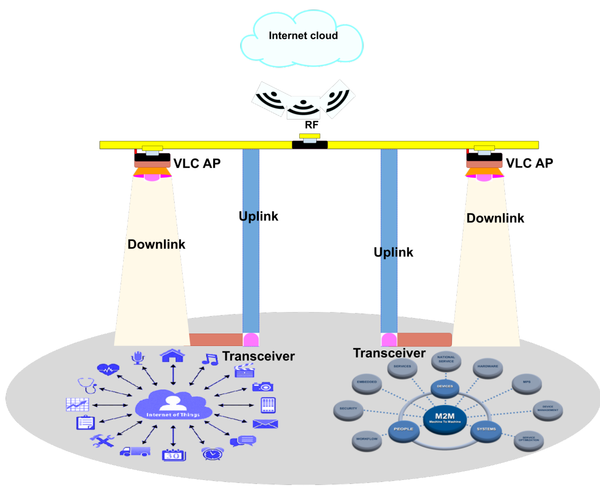

Fig. 1. A multi-channel VLC access system based on an indoor scenario.

A generalized M2M VLC based data system model is depicted in Fig. 1. It is worth important to note here that the information is gotten from the internet cloud (backbone network) using RF, it shows the VLC transmissions components and their converting VLC APs. Light emitting diodes used as light sources (transmitter) and photo-diodes receivers. For communications like houses or building of offices, a converting device like a solar panel is installed at the top of such place which is capable of converting the light rays and re-transmitting them for indoor communication.

IV. Preliminary Analysis

A. M2M VLC Channel Description

The proposed access system is made up of transceivers supplied with information from a RF back haul. The transmitter comprised of LEDs which produces light rays encoded to carry the information, the information is now used by the various machines (devices) put in place for communication.
The proposed system could be deployed in two principal environment, indoor and outdoor environment. For outdoor environment, we make use of laser diodes (LDs) to transmit the message. The indoor make use of LEDs to maintain connection with the devices. Both environments uses a peer-to-peer topology and hence could be used for lighting. A couple of scenarios could be applied here, like multiple LDs and LEDs and single LDs and LEDs. With some advanced modulation schemes such as on-off keying (OOK) [21], variable pulse position modulation (VPPM) [21], orthogonal frequency division multiplexing (OFDM) [21], using phase shift keying (PSK) in its subcarriers, to mention only a few. With the system design using a coding technique like forward error correction.

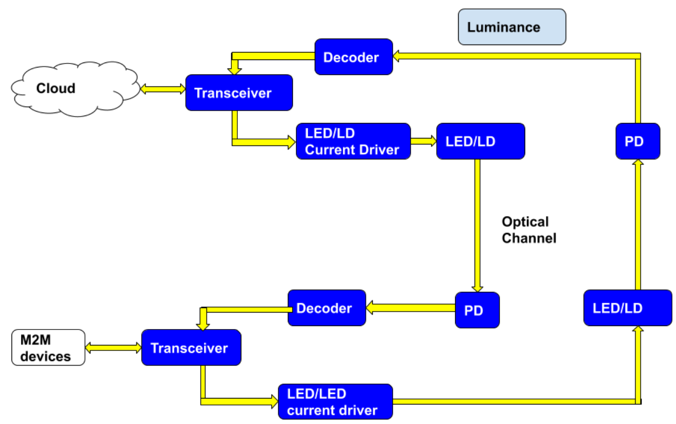

Fig. 2. A block diagram for M2M VLC based channel model for indoor and outdoor scenario

In this paper, we propose our analysis based on an amplify forward (AF) strategy, where no processing of data is involved, in case of re-transmission. The light signals are detected and directly converted to a corresponding current and to the power of the LEDs or LDs. The outdoor M2M VLC based channel can be influenced by several impairments sources including haze, fog, dust, rain, and sunlight. The worst SNR received being that at noon. Considering that sunlight is principal source light, we model the system with a Gaussian normal distribution.

$$S_o = H_o S + N_o, \tag{1}$$

where S is the original message, S_o is the message at the LD receiver and N_o the additive white Gaussian noise (AWGN).

The outdoor part is a single mode Gaussian beam stochastic channel governed by [22]

$$H_{LoS(o)} = \frac{2A_l e^{-\gamma L}}{\pi \theta^2 L^2}, \tag{2}$$

where A_l is the effective laser receiver area, θ is the small angle beam divergence, L is the transmission range and γ is the intensity of the attenuation coefficient.
The M2M VLC based indoor environment is also model in the same manner as the outdoor with the introduction of the shot noise and thermal noise. The indoor channel

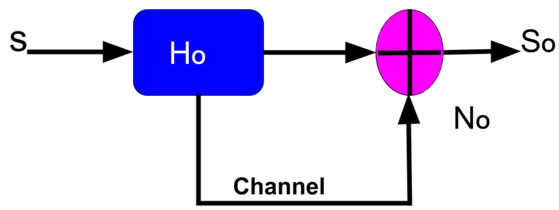

Fig. 3. Simplified channel modeled of LD systems in an outdoor environment.

assumes the additive white Gaussian response while taking into consideration the non line-of-sight (NLoS)

$$S_i = H_i S + N_i, \quad (3)$$

where S is the original message, S_i is the message at the LED receiver and N_i the additive white Gaussian noise AWGN.
It is important to note that both LD and LED lights uses similar models to transmit data and both obey the optical propagation principle [23], [24]. The transfer function of the indoor channel is given by,

$$H_{o,i} = H_{LoS(o,i)} + H_{NLoS(o,i)}, \quad (4)$$

For indoor both LoS and NLoS path are considered, while for outdoor, only LoS is considered.

$$S_i = H_i S + N_i, \quad (5)$$

where S is the original message, S_i is the message at the LED receiver and N_i the additive white Gaussian noise (AWGN).

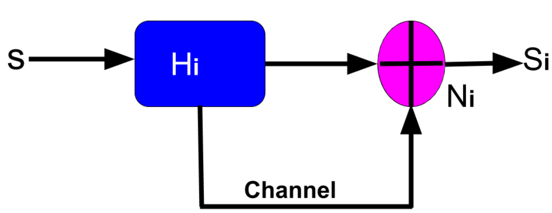

Fig. 4. Simplified channel modeled of LED systems in an indoor environment.

The equations describing LoS and NLoS are well elaborated in Eqs.(4) and (5).

$$H_{LoS(i)} = \frac{A_r(\eta+1)\cos^{\eta}\phi\cos\varphi}{2\pi d^2} e^{-j2\pi f t_{LoS}}, \quad (6)$$

and

$$H_{NLoS(i)} = \frac{A_r \rho e^{-j2\pi f t_{Diff}}}{A_{room}(1-\rho)(1+\frac{jf}{f_0})}, \quad (7)$$

respectively, where A_r and A_{room} are the effective PD area and the room area, respectively, ϕ is the irradiance angle, ρ is the average walls reflectivity, η, is the lambertian order given by $\eta = -\log_2(2)/\log_2(\theta 1/2)$ and φ the incidence angle. Note that f_o is the dB cut-off frequency of a pure diffuse channel. The transfer function of the M2M VLC based indoor system is the summation of the LoS and NLoS links, given by

$$H_i = \frac{A_r(\eta+1)\cos^{\eta}\phi\cos\varphi}{2\pi d^2} e^{-}j2\pi f t_{LoS} + \frac{A_r \rho e^{-}j2\pi f t_{NLoS}}{A_{room}(1-\rho)(1+\frac{jf}{f_0})},$$

B. Noise and Interference Scenario

In this paper, since M2M assumes the environment VLC, there are principal noise sources. shot (Quantum), thermal heat from electronic components (dark current) and background radiation noises especially in indoor VLC environment. In case of short noise, it is that generated from Bose-Einstein statistics with coherent light source represented by Poisson distribution.
It is worth noting here, that shot noise is comprise of that generated from LoS rays, another from reflected lights and thirdly that generated from background light. Thermal noise is that generated by receiver circuitry elements. AWGN is used in modeling the channels. Again, due to multi-path propagation, another noise arises in the form of interference. Here, another light carrying the same message reaches the receiver at a slightly different time especially in VLC indoor environment.

C. System Geometry and M2M VLC Based Signal To Noise Ratio

This subsection proposes a geometric model of a chosen light source in our M2M VLC based system and how a mobile device or machine in a cell could possibly transit to another adjacent cell while maintaining the communication. The model is described by considering a threshold outage probability boundary. In Fig. 5, the mobile device could be require moving from one cell to another while still maintaining communication with other many devices in the M2M VLC based system. There are a couple of handover techniques in RF systems which its counterpart VLC system can be enumerated from. The easiest and simplest handover is the received signal strength (RSS). In RSS, handover only occurs when the signal strength is stronger in the new cell compared to the cell the user is currently connected to.

In our system geometry, assuming all the sources are placed on the same plane. We define some parameters, d as equal distance separating independent light sources. r is the radius of any identical sphere. In this paper, we proposed an optical atto-cell for an indoor visible light M2M communication in

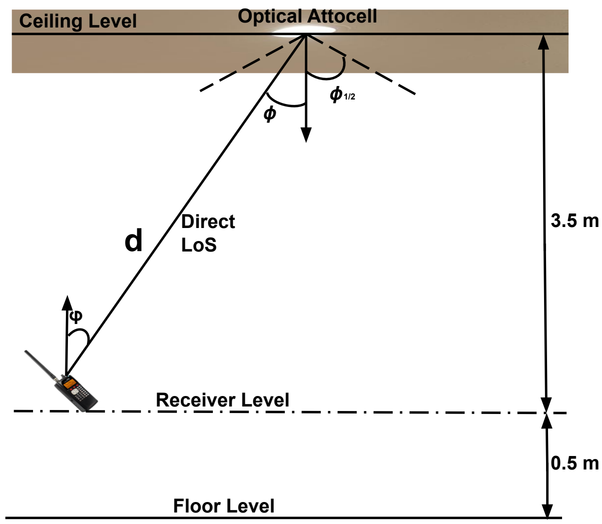

Fig. 5. A geometry system model for single cell.

an acoustic room with $10 \times 10 \times 4m^3$ of length, width, and height respectively with atto-cells mounted at the top of the ceiling for a 3.5 m to the receiver level, we consider a LoS as in Fig. [5].

The power consumption (P_c) of an optical atto-cell is given by:

$$P_c = K \times P_{led} \tag{8}$$

Where K is a square array of LEDs and P_{led} is the power consumption of each LED. Considering only the LoS path with its transfer function for indoor or DC gain, the optical received power at the receiver (P_r) is computed as follows:

$$P_r = H_i \times P_c \tag{9}$$

The SNR for the indoor distribution of LEDs as a result of shot and thermal noise is given by:

$$SNR = \frac{(RP_r)^2}{\sigma_{sh}^2 + \sigma_{th}^2} \tag{10}$$

where, R is the responsivity of the receiver,σ_{sh}^2 and σ_{th}^2 are the variances of shot and thermal noise respectively as shown below:

$$\sigma_{sh}^2 = 2q[RP_r + I_{bg}I_1], \tag{11}$$

$$\sigma_{th}^2 = 8\pi k T_k \eta A B^2 \left[\frac{2}{G} + \frac{2\pi\Gamma}{g_m}\eta A I_3 B\right] \tag{12}$$

Refer to [25] and [26] for the definition of previous parameters. Parameter setting for the simulation are given on the table 1 below.

TABLE I
SIMULATION PARAMETER.

Parameters	Value
Reflection coefficient	0.8
Transmitted power per LED	10W
Semi-angle at half power	10°, 70°
Height of receiver level	0.5 m
FOV	40
Refractive index	1.5
Gain of optical filter	1
Responsivity of PD, (R)	0.54
Bandwidth factor (I_2)	0.562
Bit rate, B	30 Mb/s
Absolute Temperature, (T_k)	298 K
Fixed capacitor per unit area, (ζ)	112pF/cm^2
Detected physical area, (A_r)	1 cm^2
FET channel noise factor, (Γ)	1.5
FET transconductance, (g_m)	30 mS
Bandwidth factor, (I_3)	0.0868

V. Simulation and Results

As shown in Fig. 6, it illustrates the relationship of frequency, and SNR distribution. The SNR is distributed at different data rates. The presence of noise influences the rate at which data is transmitted.

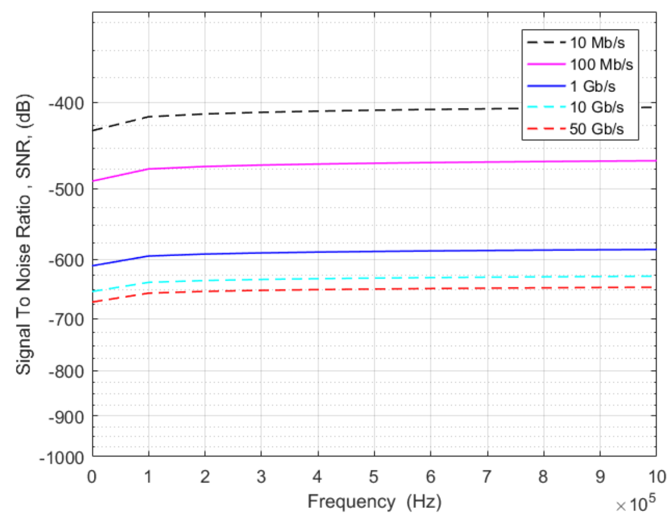

Fig. 6. Average received SNR for multiple values of the bit rate B of the channel against frequency.

As illustrated in Fig. 7, For multiple value of bit rate, the figure illustrate the relationship between the SNR and the semi-angle half power.

VI. Conclusion

M2M VLC based is an important applicable concept of information and communication technology. M2M VLC based can be used extensively as one of IoTs applications. Although, there are many challenges of M2M VLC based, one of them which is heterogeneity of the communication network devices. M2M VLC based presents one of the most reliable secured and viable communication in IoTs with a proven tract of releasing

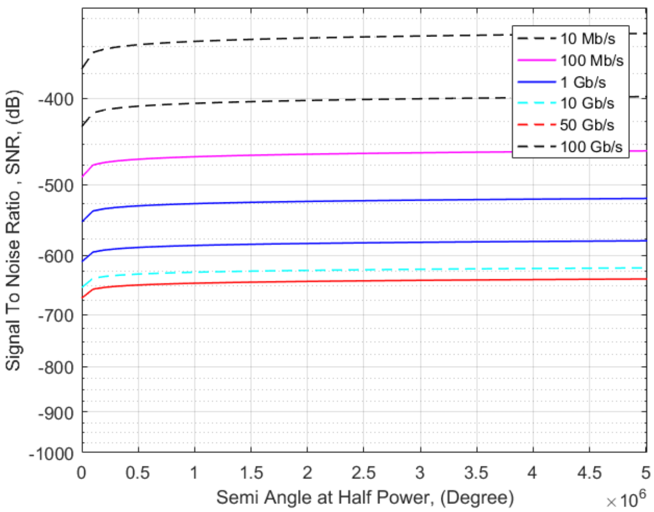

Fig. 7. Average received SNR for multiple values of the bit rate B of the channel against semi angle at half power.

high data rates and serves as a solution to already congested, overcrowded electromagnetic spectrum. This paper proposed underlying principles of M2M VLC based, M2M VLC based features, attempted standardization with their applications, status of research and progress in M2M VLC based. The performance parameter essential for establishing a successful M2M VLC based network are presented. In this paper, we make use of atto-cells model with variable parameters with best possible SNR distribution observed. The performance was evaluated an analyze for different values of semi angle at half power angles. It is shown that a data rate of 100 Gb/s can be achieved.

In the future, further simulation of outage probability and bit error rate could be done. Also, hardware prototype can be implemented in the form of arduino-based or field programmable gate array-based modules and microprocessors. The results could be practically implemented with integrated circuits technology.

REFERENCES

[1] Trio, A. Salman, S. Fuada, F. Ismail, and E. Setiawan, "Machine to machine communication (M2M) based on visible light communication (VLC)," November 2018.

[2] A. Rajaram, D. N. K. Jayakody, K. Srinivasan, B. Chen, and V. Sharma, "Opportunistic-harvesting: RF wireless power transfer scheme for multiple access relays system," *IEEE Access*, vol. 5, pp. 16 084–16 099, August 2017.

[3] K. Ishibashi, H. Ochiai, and V. Tarokh, "Energy harvesting cooperative communications," in *IEEE 23rd International symposium on personal, indoor and mobile radio communications*, September 2012, pp. 1819–1823.

[4] M. H. Khadr, H. A. Fayed, A. A. E. Aziz, and M. H. Aly, "Bandwidth extension of an enhanced SNR with a higher light uniformity of a phosphorescent white LED based visible light communication system," in *10th International symposium on communication systems, networks and digital signal processing (CSNDSP)*, July 2016, pp. 1–6.

[5] Do, Trong-Hop and Hwang, Junho and Yoo, Myungsik, "Analysis of the effects of LED direction on the performance of visible light communication system," *Photonic network communications*, vol. 25, pp. 60–72, Febrauary 2012.

[6] Chen, Yi and Sung, Chi Wan and Ho, Siu-Wai and Wong, Wing Shing, "BER analysis and power control for interfering visible light communication systems," *Optik - International journal for light and electron optics*, vol. 151, pp. 98–109, October 2017.

[7] Y. Chen, C. W. Sung, S. Ho, and W. S. Wong, "BER analysis for interfering visible light communication systems," in *10th International symposium on communication systems, networks and digital signal processing (CSNDSP)*, July 2016, pp. 1–6.

[8] Su-il Choi, "Analysis of VLC channel based on the shapes of white-light LED lighting," in *Fourth International conference on ubiquitous and future networks (ICUFN)*, July 2012, pp. 1–5.

[9] M. Emmelmann, "Influence of velocity on the handover delay associated with a radio-signal-measurement-based handover decision," in *IEEE 62nd Vehicular technology conference,*, vol. 4, October 2005, pp. 2282–2286.

[10] I. Miya and Y. Kajikawa, "Base station layout support system for indoor visible light communication," pp. 661–666, October 2010.

[11] A. M. Vegni and T. Little, "Handover in VLC systems with cooperating mobile devices," in *International conference on computing, networking and communications*, January 2012, pp. 126–130.

[12] H.-J. Kim, S. V. Tiwari, and Y.-H. Chung, "Multi-hop relay-based maritime visible light communication," *Chinese Optics Letters*, vol. 14, pp. 050 607–50 611, May 2016.

[13] A. R. Ndjiongue, T. Ngatched, O. Dobre, and A. Armada, "VLC-based networking: Feasibility and challenges," September 2019.

[14] A. R. Ndjiongue, T. Ngatched, and H. Ferreira, "Access telecommunication systems using VLC technology: Cascaded LD-LED channel analysis," pp. 1–6, December 2018.

[15] S. M. Nlom, A. R. Ndjiongue, and K. Ouahada, "Cascaded PLC-VLC channel: An indoor measurements campaign," *IEEE Access*, vol. 6, pp. 25 230–25 239, April 2018.

[16] R. C. Fon, A. R. Ndjiongue, and K. Ouahada, "Cascaded optic fibre–visible light communications: Channel model and analysis," in *International conference on advances in big data, computing and data communication systems (icABCD)*, August 2019, pp. 1–6.

[17] A. R. Ndjiongue, H. Ferreira, and T. Ngatched, "Visible light communications (VLC) technology," *Wiley encyclopedia of electrical and electronics engineering*, pp. 1–15, June 2015.

[18] R. D. Roberts, S. Rajagopal, and S. Lim, "IEEE 802.15.7 physical layer summary," in *IEEE GLOBECOM workshops (GC Wkshps)*, December 2011, pp. 772–776.

[19] D. Niyato, X. Lu, and P. Wang, "Machine-to-machine communications for home energy management system in smart grid," *Communications magazine, IEEE*, vol. 49, pp. 53 – 59, May 2011.

[20] Cisco, "Cisco visual networking index: Global mobile data traffic forecast update 2014-2019," *White Pap.*, pp. 1–42, January 2014.

[21] M.-A. Khalighi and M. Uysal, "Survey on free space optical communication: A communication theory perspective," *IEEE Communications surveys and amp tutorials*, vol. 16, pp. 2231–2258, November 2014.

[22] D K Borah, A. Boucouvalas, C. Davis, S. Hranilovic, and K. Yiannopoulos, "A review of communication-oriented optical wireless systems," *EURASIP Journal on wireless communications and networking*, vol. 2012, December 2012.

[23] V. Jungnickel, V. Pohl, S. Nonnig, and C. Helmolt, "A physical model of the wireless infrared communication channel," *IEEE Journal on selected areas in communications*, vol. 20, pp. 631 – 640, April 2002.

[24] V. Pohl, V. Jungnickel, and C. Helmolt, "A channel model for wireless infrared communication," vol. 1, September 2000, pp. 297 – 303.

[25] Abdullah, Mohammad Faiz Liew and Green, R.J. and Leeson, Mark, "Optical wireless communication front-ends," in *High frequency postgraduate student colloquium*, October 2004, pp. 3 – 8.

[26] D. Tsonev, S. Videv, and H. Haas, "Light fidelity (Li-Fi): Towards all-optical networking," in *Broadband access communication cechnologies VIII*, vol. 9007, December 2013, p. 900702.