Fuzzy Logic Based Network Selection in Hybrid OCC/Li-Fi Communication System

Moh. Khalid Hasan*, Md Shahjalal, Mostafa Zaman Chowdhury, Md. Tanvir Hossan, and Yeong Min Jang**
Department of Electronics Engineering, Kookmin University, Seoul, South Korea
Email: *khalidrahman45@ieee.org, **yjang@kookmin.ac.kr

***Abstract*—For being highly energy efficient and inexpensive, the use of current commercial LEDs for transmitting data is considered as a significant milestone in the area of optical wireless communications. Light-fidelity (Li-Fi) and optical camera communications (OCC) are two latest technologies which use LED as transmitter, with PD and camera as receivers, respectively. Currently, Li-Fi is emerged as highly promising as it supports high data rate and security. But it suffers from some limitations, e.g., short communication distance, low signal-to-interference-plus-noise ratio (SINR) etc. OCC can overcome these limitations, but it only supports lower data rate. Therefore, to provide proper solution, we propose a hybrid OCC/Li-Fi system. We are not going to use both the technologies at the same time, rather access point is selected based on fuzzy logic, considering different application scenarios. Furthermore, at the end of this paper, the performance of the selection mechanism is discussed briefly.**

Index Terms: Optical camera communications (OCC), light-fidelity (Li-Fi), fuzzy logic (FL), network selection (NS), hybrid network.

I. Introduction

In recent times, visible light communication (VLC) has added a new dimension in the world of next generation wireless communication technologies for becoming very useful in terms of both data rate and reliability. It is widely acceptable as it aids to find relief from the spectrum congestion associated with current radio frequency (RF) as well as for its high security, low latency, low power consumption, and high quality of experience [1]-[4].

Optical camera communication (OCC) and light-fidelity (Li-Fi) both are subsets of VLC. Li-Fi is a wireless networking system that uses a photo detector (PD) to receive data from LED transmitter. A concentrator is employed in front of PD to enhance the level of received optical power [1]. Despite being a high speed communication technology, Li-Fi is criticized for its distance limitation as well as high interference characteristics of conventional PDs. OCC is a similar technology to Li-Fi where existing lighting technologies is used as transmitter. However, the main difference is it uses a camera to receive the optical signals. Since currently we are highly habituated with camera mounted smartphones, the use of this camera for data reception is found to be very promising among different wireless technologies [5] - [8]. OCC is an excellent solution of long distance line-of-sight (LoS) communication and offers several useful features, e.g., low interference, high security, excellent signal-to-noise ratio (SNR), and high stability against changing communications distances [9]-[12]. But OCC is not rich yet in terms of data rate, which is one of the main limitation compared to Li-Fi.

Motivated by the limitations offered by OCC and Li-Fi, a hybrid OCC/Li-Fi system is proposed in this article. Only one access point is selected in a given time which is based on fuzzy logic (FL). The main advantage of using FL is its capability of solving a complex question by utilizing a series of if/then rules [13]. The proposed hybrid architecture deals with the possible solutions to enhance the quality-of-service (QOS) for users as well as proper utilization of the overall amenities given by each individual technologies. The selection of access point is finalized considering some scenarios, such as

- In daytime, Li-Fi cannot be used in outdoor because of sunlight, which is responsible for causing extreme interference. OCC access point is selected in this case. However, during nighttime, the network selection is done by applying FL.
- For scenarios where higher data rate is the prime concern (e.g., high speed internet for downloading larger media files), Li-Fi is chosen as access point.
- There are some scenarios where higher SINR (resulting in low bit error rate) is more important rather than higher data rate, e.g., indoor/outdoor positioning, sending any identification number or address, real time communication etc. In these cases, OCC is selected in the hybrid network.
- For scenarios where long distance communication is an important issue, OCC is chosen over Li-Fi. These scenarios include outdoor car-to-car/car-to-infrastructure communications, localized advertising, underwater communication etc.

The rest of the article is arranged as follows; Section II represents the system overview and an analysis on channel model, which includes SINR measurement for both technologies. The FL based selection mechanism is explained in section III. Section IV discusses the performance of the selection method for different scenarios. A brief summarization of our work is provided in the final section.

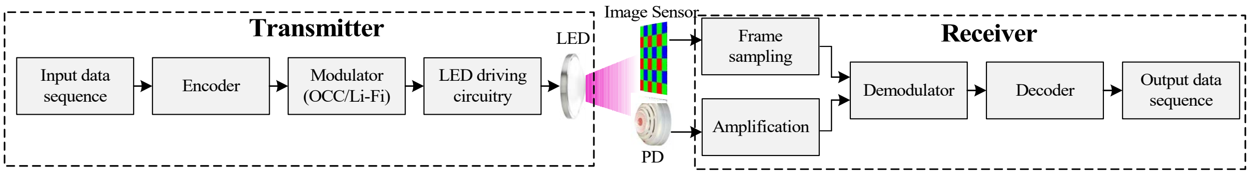

Fig. 1. Block diagram of hybrid OCC/Li-Fi architecture.

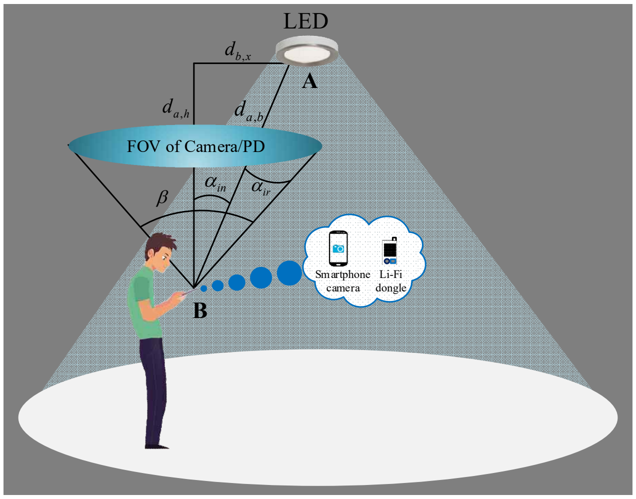

Fig. 2. Data transmission model for hybrid network.

II. System Overview

A. Hybrid system architecture

A hybrid OCC/Li-Fi network is proposed in this article. Multiple users can be served by the hybrid system which is suitable for all cases whether the user is roaming or remains stationary. Each user is connected to an access point in a given time so that it won't cause any interference although OCC and Li-Fi both technologies use the same spectrum. A block diagram of our proposed system is shown in Fig. 1 which illustrates the operating principle of both Li-Fi and OCC. Same LED is used for both cases. However, main difference includes the modulation frequency which is completely different for both technologies. There is a critical flickering rate of LED beyond which cameras cannot detect the LED signal [14]. This particularly limits the overall data rate for OCC. The flickering should not be observed by human eyes as well, which is approximately 100 Hz [15]. For these reasons, the modulation frequency for OCC is considerably different from Li-Fi.

B. Channel model

Fig. 2 shows an example of indoor hybrid system, where transmitter and receiver are shown at A and B, respectively. For a VLC system, the path for optical signal transmission has two components: line-of-sight (LoS) and non-line-of-sight (NLoS). Applying region of interest (RoI) signaling technique, the impact of the reflection component is mitigated for OCC [3]. In case of Li-Fi, the reflection component is disregarded too, as our baseband modulation bandwidth W is 20 MHz which does not exceed the maximum allowable value [13]. The channel for optical signal transmission can be modeled by lambertian radiant intensity [16], [17]

$$R_o(\alpha) = \frac{(m_l + 1)\cos^{m_l}(\alpha_{ir})}{2\pi} \tag{1}$$

where α_{ir} represents the angle of irradiance of the LED. m_l is the Lambertian emission order, which is a function of the radiation angle $\Psi_{1/2}$ at which the radiation intensity is half of that in the main-beam direction. m_l is defined as

$$m_l = -\frac{\ln 2}{\ln(\cos\Psi_{1/2})} \tag{2}$$

We assume the Euclidean distance between the LED access point and camera receiver is $d_{a,b}$, which is found from the horizontal distance $d_{b,x}$ and the vertical distance $d_{a,h}$ ($d_{a,b} = \sqrt{d_{a,h}^2 + d_{b,x}^2}$). The overall dc channel gain for OCC is formulated as [14]

$$G_{a,b} = \frac{R_o(\alpha) A_c}{d_{a,b}^2} g_{op} g_{con} cos(\alpha_{in}) \Delta \tag{3}$$

where α_{in} implies the corresponding angle of incidence, g_{op} represents the gain of the optical filter, g_{con} is a function of refractive index and concentrator semiangle called concentrator gain, and Δ is a rectangular function whose value implies that the channel gain is zero if the LED remains outside of the field of view (FOV) of camera receiver. If β is the FOV of camera/PD, then Δ is represented as

$$\Delta = \begin{cases} 0, & \alpha_{in} \geq \beta \\ 1, & \alpha_{in} < \beta \end{cases} \tag{4}$$

A_c is defined differently for different VLC technologies. As PD is used as receiver for Li-Fi, A_c is defined as the detector physical area sensitive to light. However, in terms of OCC, A_c denotes the projected area of the image of LED on the image sensor of camera. If A_l represents the physical area of LED, then the projected area is

$$A_c = \frac{A_l f_o^2}{d_{a,b}^2} \tag{5}$$

where f_o denotes the focal length of camera.

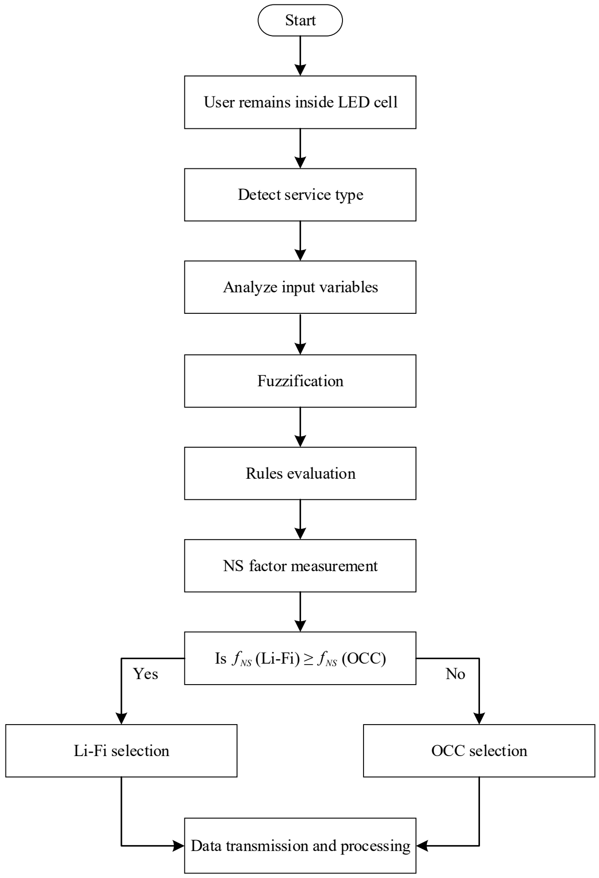

Fig. 3. FL based access point selection.

Li-Fi systems are greatly affected by interferences created from sunlight and other ambient light sources. Currently LED infrastructures are densely formed inside indoor environments which make it possible to generate extreme interference for a user reducing the overall signal-to-noise plus interference ratio (SINR) to a great extent. The SINR for a Li-Fi system is given by the following equation

$$SINR = \frac{\left(RP_t G_{A,B}\right)^2}{N_o W + \sum_{i=0}^{N}\left(RP_t G_{i,B}\right)^2} \tag{6}$$

where P_t represents the transmitted optical power, R denotes the optical to electrical conversion efficiency which is measured in amperes per watt, N_o denotes the noise spectral density, N is the total number of neighbor LEDs, i indicates a specific interfering LED, and $G_{i,B}$ indicates the channel gain between user and the interfering LED. In case of OCC, the bandwidth W is replaced by the sampling rate of camera f_r. As mentioned earlier, due to the nature of camera image sensor, it is possible to spatially separate the noise elements by introducing ROI techniques, which significantly contributes to achieve high SINR for OCC [3].

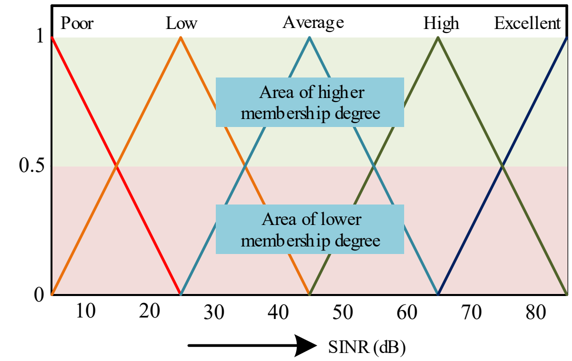

Fig. 4. Fuzzification process for SINR.

III. FL BASED NETWORK SELECTION

A fuzzy based network selection method is proposed in this section. Instead of making decision for choosing a network in a hybrid system in terms of Boolean logic (only true or false), FL based selection will assign truth values of variables ranged from 0 to 1. A particular network is selected based on the service requirement. OCC is enabled in the initial scenario. A decision making factor, called network selection (NS) factor, is evaluated to assist the selection mechanism. The proposed selection method is illustrated in Fig. 3. We apply Mamdani fuzzy inference process to evaluate our proposed scheme which includes three principle steps: fuzzification of input variables, rules evaluation and defuzzification.

Fuzzification indicates the process of transforming the crisp inputs into degrees of functional blocks through utilization of the different types of fuzzifiers, referred as membership functions. We used four input variables in the network selection mechanism: data rate requirement, SINR requirement, receiving power characteristics and communications distance. The fuzzy sets are categorized differently for these membership functions. Fig. 4 shows an illustration of fuzzification of SINR requirement which is represented by five triangular membership functions: poor, low, average, high, and excellent, and distributed from 5 to 85 dB. The triangular membership function is given by three parameters {a,b,c}

$$T(x;a,b,c) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \tag{7}$$

Other inputs are fuzzified by same technique. However, the number of membership functions is varied. After fuzzifying the inputs, the rules are evaluated to specify the score allocation for the network selection mechanism. Rules are guidelines generated based on the membership functions, and serve in a basis of why we choose a specific network in a

Table 1: System parameters for simulation

Transmitter parameters	
LED radius, a_l	5 cm
Transmitted optical power, P_t	10 W
Half-intensity radiation angle, $\Psi_{1/2}$	60°
Gain of optical filter, g_{op}	1.0
Receiver parameters (Li-Fi)	
Physical area of PD	1 cm^2
Gain of optical concentrator, g_{con}	1.5
Responsivity, R	0.53 A/W
Receiver parameters (OCC)	
Image sensor size	6×4 (3:2 aspect ratio)
Pixel edge length, ρ	2 µm
Frame rate, f_r	30 fps
Focal length, f_o	6 mm
Responsivity, R	0.51 A/W

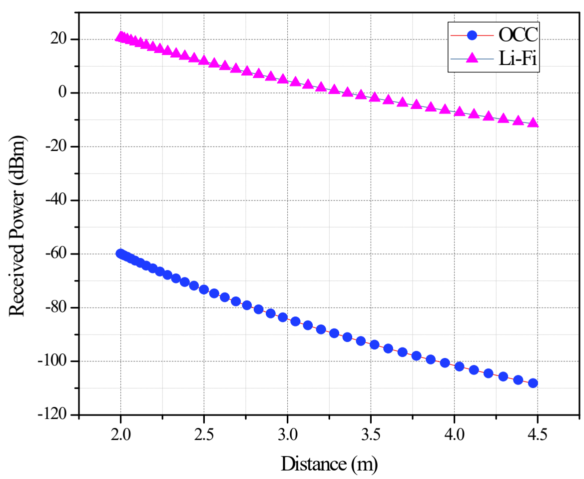

Fig. 5. Distribution of received power of Li-Fi and OCC

specific kind of service scenario. For example, a user in an indoor environment needs to use VLC for localization. The user requires high SINR, but high data rate is not mandatory. For this reason, OCC is chosen as access point. Here distance is not a matter of concern as well. However, in another case, let's say the user needs to download a larger video, then it needs to achieve high data rate instead of high SINR, consequently it will choose Li-Fi. But when the distance is considerably large, the user will still be allocated to OCC access point instead of Li-Fi. We define two output levels for the networks in the hybrid system where both levels are constructed by triangular membership functions. After we achieve final score, which is called network selection (NS) factor and represented as f_{NS}, will be evaluated to select the appropriate access point and the process is called defuzzification. In fact, the access point is selected whose f_{NS} is better in the corresponding scenario.

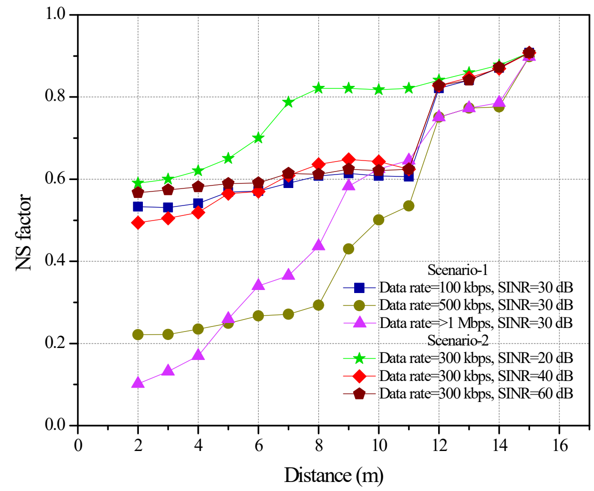

Fig. 6. NS factor variation of OCC

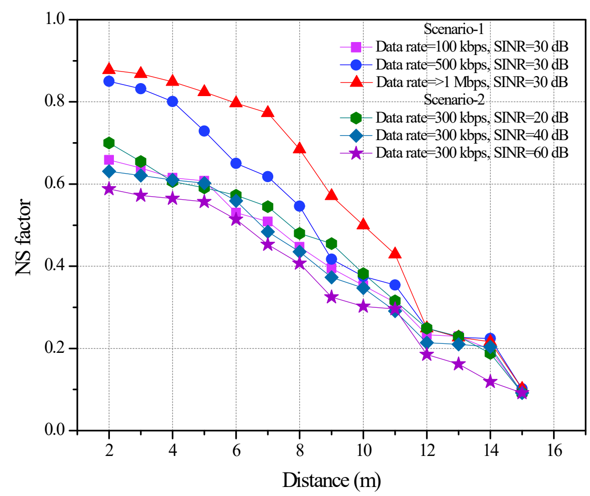

Fig. 7. NS factor variation of Li-Fi

IV. Performance Evaluation

To evaluate the performance of our proposed system, we considered two scenarios. We assume user is moving away from the LED access point in both scenarios. The specifications of parameters used for simulation are arranged in Table 1. As shown in Fig. 5, the value of received power decreases exponentially with increasing distance from user to LED. To avoid complexity, we consider that user is receiving average power for both technologies. In terms of different application scenarios, the value of SINR changes with the variation of number of neighboring LEDs.

Figures 6 and 7 represent the NS factor allotment in the hybrid system with different SINR requirements and data rate. It is clearly evident that in the initial case when SINR requirement is not high, the NS factor of Li-Fi is much higher for lower distance. When the distance between user and LED increases, the NS factor of Li-Fi goes down. When SINR requirement is higher, OCC is slightly more preferable if the data rate requirement is average in this case. Li-Fi has a higher NS factor for higher data rates, where OCC is chosen for high distances.

V. CONCLUSION AND FUTURE RESEARCH

In this paper, an access point selection method for a hybrid OCC/Li-Fi system is proposed. The selection mechanism is done by using fuzzy logic. The main focus includes selecting one network in a given time considering the application scenario and technical requirements. Two scenarios are considered in this article and an access point selection factor, called NS factor, is measured for each network based on FL. The network is chosen in a particular environment whose NS factor is higher. Performance is evaluated taking different SINR requirements and data rates into account. Future research will involve implementation in different environments and testing the optimality of our proposed scheme comparing with the existing hybrid systems.

VI. ACKNOWLEDGEMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIT) (No. 2017-0-00824, Development of Intelligent and Hybrid OCC-LiFi Systems for Next Generation Optical Wireless Communications).

REFERENCES

[1] M. Z. Chowdhury, M. T. Hossan, A. Islam and Y. M. Jang, “A comparative survey of optical wireless technologies: architectures and applications,” *IEEE Access,* vol. 6, pp. 9819-9840, Jan. 2018.

[2] P. Ji, H. M. Tsai, C. Wang and F. Liu, “Vehicular visible light communications with LED taillight and rolling shutter camera,” in *Proc. IEEE 79th Vehicular Technology Conference (VTC Spring)*, Seoul, May 2014.

[3] T. Nguyen, A. Islam, M. T. Hossan, and Y. M. Jang, “Current status and performance analysis of optical camera communication technologies for 5G networks,” *IEEE Access,* vol. 5, no. 1, pp. 4574-4594, Apr. 2017.

[4] Z. Ghassemlooy, S. Arnon, M. Uysal, Z. Xu, and J. Cheng, “Emerging optical wireless communications-advances and challenges,” *IEEE J. Sel. Areas Commun.,* vol. 33, no. 9, pp. 1738-1749, Sep. 2015.

[5] M. T. Hossan, M. Z. Chowdhury, A. Islam, and Y. M. Jang, “A novel indoor mobile localization system based on optical camera communication,” *Wireless Communications and Mobile Computing,* vol. 2018, no. 2018, pp. 1-17, Jan. 2018.

[6] T. Nguyen, A. Islam, T. Yamazato, and Y. M. Jang, “Technical issues on IEEE 802.15.7m image sensor communication standardization,” *IEEE Communications Magazine,* vol. 56, no. 2, pp. 213-218, Feb. 2018.

[7] B. Liu, Z. Yan, and C. W. Chen, “Medium access control for wireless body area networks with QoS provisioning and energy efficient design,” *IEEE Transactions on Mobile Computing*, vol. 16, no. 2, Feb. 2017, pp. 422-434.

[8] A. S. M. Z. Shifat, M. Z. Chowdhury, and Y. M. Jang, “A game theoretical approach for QoS provisioning in heterogeneous networks,” *ICT Express*, vol. 1, no. 2, pp. 90-93, Sep. 2015.

[9] N. Saha, M. S. Ifthekhar, N. T. Le and Y. M. Jang, “Survey on optical camera communications: challenges and opportunities,” *IET Optoelectronics,* vol. 9, no. 5, pp. 172-183, Oct. 2015.

[10] T. Yamazato et al., “Vehicle Motion and Pixel Illumination Modeling for Image Sensor Based Visible Light Communication,” *IEEE Journal on Selected Areas in Communications,* vol. 33, no. 9, pp. 1793 - 1805, Sept. 2015.

[11] Y. Goto et al., “A new automotive VLC system using optical communication image sensor,” *IEEE Photonics Journal,* vol. 8, no. 3, pp. 1-17, Jun. 2016.

[12] N. T. Le, M. A. Hossain, and Y. M. Jang, “A survey of design and implementation for optical camera communication,” *Signal Processing: Image Communication,* vol. 53, pp. 95-109, Apr. 2017.

[13] Y. Wang and H. Haas, “Dynamic load balancing with handover in hybrid Li-Fi and Wi-Fi networks,” *Journal of Lightwave Technology,* vol. 33, no. 22, pp. 4671-4682, Nov. 2015.

[14] R. D. Roberts, “Undersampled frequency shift ON-OFF keying (UFSOOK) for camera communications (CamCom),” in *Proc. 22nd Wireless and Optical Communication Conference*, Chongqing, 2013.

[15] P. Luo et al., “Experimental demonstration of RGB LED-based optical camera communications,” *IEEE Photonics Journal,* vol. 7, no. 5, pp. 1-12, Oct. 2015.

[16] J. M. Kahn and J. R. Barry, “Wireless infrared communications,” *Proceedings of the IEEE,* vol. 85, no. 2, pp. 265-298, Feb. 1997.

[17] G. Pan, J. Ye, and Z. Ding, “Secure hybrid VLC-RF systems with light energy harvesting,” *IEEE Transactions on Communications,* vol. 65, no. 10, pp. 4348-4359, Oct. 2017.