SVM-based Network Access Type Decision in Hybrid LiFi and WiFi Networks

Kaixuan Ji†‡, Tianqi Mao†, Jiaxuan Chen†, Yuhan Dong‡ and Zhaocheng Wang†‡
†Beijing National Research Center for Information Science and Technology,
Department of Electronic Engineering, Tsinghua University, Beijing 100084, China
‡Division of Information Science and Technology,
Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China

***Abstract*—In indoor environment, a hybrid network consisting of light fidelity (LiFi) and wireless fidelity (WiFi) is capable of retaining both the high-speed data transmission and the ubiquitous coverage, where the network access type of users can be optimized to improve the performance. Since visible light communication mainly depends on the line-of-sight (LoS) transmission, it is susceptible to channel blockage, which should be considered by users to select the appropriate type of network access. In the existing literature, LiFi channel blockage parameters are regarded as known for users to determine the access type. However, in practical scenarios, the estimation of blockage parameters lags behind their variations, and users can not get the real-time blockage information. In this paper, a support-vector-machine-based (SVM-based) network access type decision scheme is proposed in hybrid LiFi and WiFi networks. By taking the correlation of blockage parameters between adjacent periods into account, SVM is adopted to achieve high equivalent data rate when accurate blockage parameters are unknown. Simulation results demonstrate that the proposed scheme outperforms the considered benchmarks under different scenarios in terms of the equivalent data rate performance.**

***Index Terms*—Hybrid network, light fidelity (LiFi), wireless fidelity (WiFi), network access type decision, support vector machine (SVM).**

I. Introduction

With the rapid growth of service demands, data traffic in indoor wireless networks is explosively increasing [1]. As a promising complementary technology for radio frequency (RF) communication [2], light fidelity (LiFi) has been rapidly developed in recent years, which modulates data on the high-frequency visible light waves using light emitting diodes (LEDs), and employs photodiodes (PDs) to detect the received optical signals [3]. Compared with traditional wireless fidelity (WiFi), LiFi has several appealing advantages, such as high data rate, safety to human health, and high security [4]. Moreover, owing to the wide free-licensed spectrums [5], LiFi is beneficial to overcome the radio spectrum congestion [6]. However, visible light is more easily affected by obstructions, which might lead to unstable optical communication links [7]. Therefore, the bottleneck that LiFi needs to break through is how to effectively deal with the channel blockage.

To provide high rate and stable service for mobile users, an indoor heterogeneous communication network with LiFi and WiFi has been introduced, which can achieve better performance than either LiFi or WiFi [8]. Two basic vertical handover schemes are applied in the hybrid network [9], where vertical handover (VHO) refers to the handover between LiFi and WiFi. For immediate VHO (I-VHO), the handover from LiFi to WiFi is immediately performed when a LiFi channel blockage occurs and the user will be switched back to LiFi if the blockage disappears. Though I-VHO can ensure the continuity of service access, frequent handover between LiFi and WiFi could significantly reduce the effective time of data transmission, leading to low equivalent data rate of users. The alternative solution is dwell VHO (D-VHO) [9], where a user waits for a dwell period once the LiFi connection is lost. When the dwell time expires, if the optical link is still unavailable, the user switches to WiFi, otherwise it stays in LiFi. And when the optical link is recovered, the user immediately performs VHO from WiFi back to LiFi. However, D-VHO is not suitable for the case of long-term blockage interruption. To achieve higher equivalent data rate under various channel blockage situations, the user should adopt more adaptable network access method. In [10], blockage parameters are proposed to decide three network access types. Moreover, the current blockage parameters are assumed to be known when determining the network access type. However, this assumption is not realistic since the estimation of the blockage parameters lags behind their variations.

In this paper, a support-vector-machine-based (SVM-based) network access type decision scheme is proposed, which can effectively reduce the negative impact of frequent handover and channel blockage on the data rate. The main contribution of this paper is the adoption of a more practical system model, where the user only has the previous LiFi channel blockage parameters, while the current blockage information is unknown. Intuitively, there exists the correlation among blockage parameters in adjacent periods due to the relatively regular movements of indoor users or obstacles. Hence, a mapping function between the current network access type and previous blockage information exists, which however might be implicit. SVM is capable of learning the mapping function by training. Simulation results demonstrate that the proposed scheme can achieve higher equivalent data rate for users compared with their conventional counterparts.

The rest of this paper is organized as follows. Section II introduces the system model. A detailed description of the proposed scheme is then illustrated in Section III. Section IV

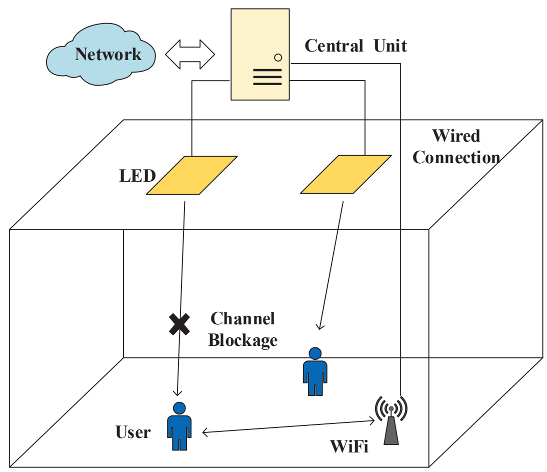

Fig. 1 The schematic diagram of an indoor hybrid LiFi and WiFi wireless communication network.

presents simulation results in terms of the equivalent data rate, and the conclusions are drawn in Section V.

II. System Model

A. Hybrid LiFi and WiFi Network

An indoor hybrid LiFi and WiFi network is considered as shown in Fig. 1, where the line-of-sight (LoS) channel of visible light can be blocked by obstacles. A WiFi access point (AP) is placed in the corner to provide coverage for the entire room, and the WiFi rate remains constant [11], denoted as r^{WiFi}. Several LEDs are installed on the ceiling, and each of them acts as a LiFi AP. The LiFi APs interfere with each other. Each user can only connect to either one LiFi AP or WiFi AP at a time. In addition, when a user accesses to LiFi, it will connect to the nearest LiFi AP. It is assumed that there is a central unit in the room deciding the network access type for each user according to its channel blockage information.

B. LiFi Channel Model

According to [12], the indoor LiFi channel can be represented by the dominant LoS channel model, and the LoS channel gain is denoted as H, which is given by

$$H = \begin{cases} \frac{(m+1)A_p}{2\pi d^2} T_s(\theta) g(\theta) \cos^m(\phi) \cos(\theta), & \theta \leq \Theta_F; \\ 0, & \theta > \Theta_F, \end{cases} \tag{1}$$

where m is the Lambertian index, A_p is the physical area of the receiver PD, d is the distance from a LiFi AP to the user's optical receiver, ϕ is the angle of irradiation, θ is the angle of incidence and Θ_F is the half angle of the receiver's field of view (FOV). $T_s(\theta)$ is the gain of the optical filter, and the concentrator gain $g(\theta)$ is given by

$$g(\theta) = \begin{cases} \frac{n^2}{\sin^2(\Theta_F)}, & \theta \leq \Theta_F; \\ 0, & \theta > \Theta_F, \end{cases} \tag{2}$$

where n is the refractive index.

When a user μ is connected to the LiFi AP α, its signal-to-interference-plus-noise ratio (SINR) can be expressed as [11]

$$\text{SINR}_{\mu,\alpha} = \frac{(\gamma P_t H_{\mu,\alpha})^2}{N_0 B + \sum(\gamma P_t H_{\mu,else})^2}, \tag{3}$$

where γ is the optical to electrical conversion efficiency, P_t is the optical power of the transmitted signals at each LiFi AP, N_0 is the noise power spectral density and B is the modulation bandwidth of the LED. $H_{\mu,\alpha}$ is the optical channel gain between user μ and LiFi AP α and $H_{\mu,else}$ is the optical channel gain between user μ and all the other LiFi APs.

When optical OFDM is employed, due to the intensity modulation and direct detection used in LiFi, only real-valued signals can be transmitted to receivers [13]. Hence, Hermitian symmetry should be satisfied for OFDM symbols, and only half of the sub-carriers are used for data transmission. Consequently, the achievable data rate between user μ and LiFi AP α can be expressed as [4] [11]

$$r^{\text{LiFi}} = \frac{B}{2} \log_2(1 + \text{SINR}_{\mu,\alpha}). \tag{4}$$

C. LiFi Channel Blockage

Since visible light LoS channel can be blocked by obstacles, to measure LiFi channel blockage information, there are two key parameters [10]: occurrence rate and occupation rate. It is assumed that the LiFi channel blockage parameters of users remain constant for a fixed short period denoted as T. Occurrence rate describes the times of channel blockages happened during the period T, and occupation rate is the ratio between the period of time when a user experiences channel blockage and T. For simplicity, this time period T is defined as a state. It is assumed that users are considered static in each state. Meanwhile in different states, the user's position is randomly distributed in the room.

III. SVM-based Network Access Type Decision

An SVM-based network access type decision scheme is proposed, named as D-SVM. In the D-SVM scheme, indoor users collect channel information and transmit to the central unit during the training phase, which constructs the sample dataset to train a nonlinear SVM model. In the operation phase, the user first transmits the currently known information to the central unit, and then the central unit uses the trained SVM model to make a decision on the network access type and feeds back to the user. Finally, the user adopts the obtained type to access the hybrid network.

A. User Scenario

The natural number n indicates the index of each state, and LiFi channel blockage occurrence rate and occupation rate of state n can be expressed by λ_n and η_n, respectively. In the traditional scheme, λ_n and η_n are regarded as known when determining the network access type [10]. In a practical scenario, a user in state n usually can not obtain λ_n and η_n, but only has the knowledge of λ_{n-1} and η_{n-1}. Hence, the traditional scheme can only use the known λ_{n-1} and η_{n-1}

to determine the access type in state n, which may lead to non-optimal access type decision.

In the proposed D-SVM scheme, the central unit updates the network access type of each user with a period of T. Although blockage parameters will be changed from state to state, these blockage parameters in the current state are affected by the channel conditions in the previous state due to regular movements of users and obstacles. Thus, in current state n, λ_n and η_n are related to their values in state $n-1$. However, this relationship might be implicit and vary with different scenarios. In this paper, SVM is introduced to learn the correlation of blockage parameters between adjacent states and to train a decision model of network access type utilizing the blockage parameters obtained from the previous state. Accodingly, when exact blockage parameters are unknown, D-SVM is capable of determining the current network access type for users and achieving high equivalent data rate.

B. Sample Set Construction

To train and test an SVM model, a large number of samples are required. The samples are divided into training samples for generating an SVM model and testing samples for verifying the effectiveness of the trained model. Specifically, a sample can be expressed by

$$\langle \boldsymbol{x}, y\rangle = \left\langle (\lambda_{n-1}, \eta_{n-1}, r_n^{\mathrm{LiFi}}), y \right\rangle, \tag{5}$$

where $\boldsymbol{x}$ is the sample input vector and y is the sample label indicating the optimal network access type. The input vector $\boldsymbol{x}$ includes the blockage occurrence rate λ_{n-1}, the blockage occupation rate η_{n-1} for the previous state and the current LiFi transmission rate r_n^{LiFi}. Since the blockage parameters for a sequence of states have been collected by the central unit during the preset time, the actual λ_n and η_n of each state n can be used to calculate the equivalent data rate of different access types. And then the central unit can determine the current optimal access type as the corresponding sample label y.

The label y is selected from the index set of network access type, which is denoted as $\{\kappa\}$. Specifically, the network access types are listed as following

- When a user connects to WiFi all the time in a state, the network access type is defined as "WiFi only" and is denoted as $\kappa = 1$.
- When a user stays in the LiFi network without handover in a state, the network access type is defined as "LiFi only" and is denoted as $\kappa = 2$.
- When a user switches from LiFi to WiFi once LiFi channel blockage occurs and switches back to the original LiFi AP after the blockage disappears in a state, the network access type is defined as "LiFi/WiFi" and is denoted as $\kappa = 3$.

For each user, its effective transmission time is the remaining time after subtracting the time of channel blockage and handover overhead. Let T_H denote the ratio between a single vertical handover overhead and the time interval T. In state n, the data transmission efficiency achieved by WiFi for a user with different access type can be denoted as $\tau_{\kappa,n}^{\mathrm{WiFi}}$, which is expressed by [10]

$$\tau_{\kappa,n}^{\mathrm{WiFi}} = \begin{cases} 1, & \kappa = 1, \\ 0, & \kappa = 2, \\ \max\{\eta_n - \lambda_n T_H, 0\}, & \kappa = 3. \end{cases} \tag{6}$$

Similarly, the data transmission efficiency achieved by LiFi for a user with different access type is denoted as $\tau_{\kappa,n}^{\mathrm{LiFi}}$, which is calculated by

$$\tau_{\kappa,n}^{\mathrm{LiFi}} = \begin{cases} 0, & \kappa = 1, \\ 1 - \eta_n, & \kappa = 2, \\ \max\{1 - \eta_n - \lambda_n T_H, 0\}, & \kappa = 3. \end{cases} \tag{7}$$

So the equivalent data rate achieved by the user with access type κ is given by

$$r_{\kappa,n} = \tau_{\kappa,n}^{\mathrm{WiFi}} r_n^{\mathrm{WiFi}} + \tau_{\kappa,n}^{\mathrm{LiFi}} r_n^{\mathrm{LiFi}}, \tag{8}$$

where r_n^{WiFi} is the constant WiFi transmission rate, and r_n^{LiFi} is the LiFi transmission rate calculated by (4) in state n.

The central unit will select the access type with the highest equivalent data rate as the sample label y for state n, which is expressed by

$$y = \arg\max_{\kappa} r_{\kappa,n}, \quad \kappa = 1, 2, 3. \tag{9}$$

C. SVM Classification

SVM is a supervised learning model, which is commonly used to solve linear classification problems by maximizing the margin on the feature space [14]. Since built sample set is linearly inseparable, a kernel functions is adopted to transform a nonlinear problem into a linear problem, which is capable of mapping the SVM training samples from the original space to the high-dimensional space where the samples are linearly separable [15]. Therefore, in D-SVM, an SVM three-classification model can be trained by LIBSVM [16], a package for solving the multiclass problem based on the nonlinear sample set.

In LIBSVM, radial basis function (RBF) is adopted as the kernel function. The optimal values of RBF parameters are selected by cross validation [15]. During the training phase, the sample input vector is the ternary parameter group $\boldsymbol{x}$ mentioned in (5), which is preprocessed by normalization. The sample label is the network access type y, which is calculated by applying (9) in the central unit. The training process of the SVM model can learn the mapping relation between $\boldsymbol{x}$ and y.

It should be noted that major overhead of the proposed D-SVM lies in the construction of sample set and the training process. Since the parameters of the trained SVM model have been stored in the central unit, after getting the input vector from a user, the central unit can determine the output network access type quickly and feed it back to the user.

IV. Simulation Results and Discussion

In this section, simulations are conducted to evaluate the performance of the proposed D-SVM scheme. When the current LiFi channel blockage parameters are unknown in practical indoor scenarios, the blockage parameters of the previous state are usually regarded as the current values

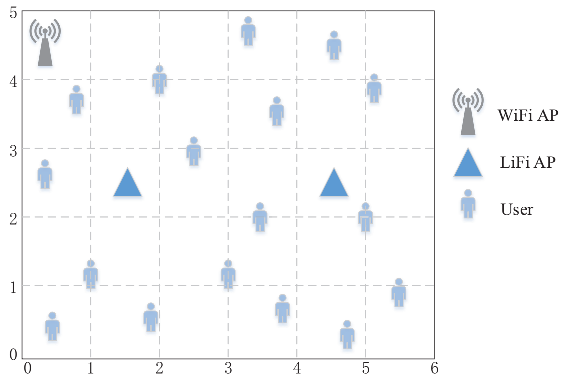

Fig. 2 The schematic diagram of Scenario 1 for emulating a small office with two LEDs.

directly for the network access type decision in the conventional scheme, which is defined as the direct decision (DD) scheme. The single access (SA) scheme uses only one network access type, such as using the "LiFi only" access type or the "LiFi/WiFi" access type. Both DD and SA schemes are used as the benchmarks for comparison.

In order to evaluate the performance of the D-SVM scheme, three various scenarios of hybrid LiFi and WiFi network are discussed in the simulations. Scenario 1 emulates a small office with two LEDs as LiFi APs, and the length, width and height of the room are 6 m, 5 m and 3.5 m, respectively (6 m $\times$ 5 m $\times$ 3.5 m). For Scenario 2, the number of LEDs in the small office is increased to four and the room size remain the same as Scenario 1. Scenario 3 changes the room size to 30 m $\times$ 20 m $\times$ 3.5 m to emulate a large warehouse or supermarket, and the number of LEDs is set to six. Fig. 2 shows the schematic diagram of Scenario 1. The plane coordinates of LEDs under three scenarios are listed in Table I.

TABLE I Plane Coordinates of LEDs under Three Scenarios

Scenarios	Plane coordinates of LEDs
Scenario1	[1.5,2.5] [4.5,2.5]
Scenario2	[1.5,1] [4.5,1] [1.5,4] [4.5,4]
Scenario3	[5,5] [15,5] [25,5] [5,15] [15,15] [25,15]

For these three scenarios, the following simulation settings are remain the same. The constant WiFi rate in the room is assumed to be 32 Mbps. The blockage occurrence rate is an arbitrary integer between 0 and 10 (times per minute), and the blockage occupation rate is set to a real number included in $\{0, 0.1, 0.2, ..., 1\}$ for the convenience of analysis. The variation of channel blockage parameters between adjacent states satisfies Markov model [17]. Therefore, λ_n and η_n are only related to λ_{n-1} and η_{n-1}, whereby two randomly generated discrete Markov matrices are used to emulate the transfer of occurrence rate and occupation rate between adjacent states. A single vertical handover overhead t is set to 500 ms, the time interval of a state T is set to 60 s and we have $T_H = t/T$. Other optical device parameters required for simulations are summarized in Table II according to [10] [11]. Without loss of generality, it is assumed that all transmitting LEDs share the identical configurations and so do all PDs at receivers.

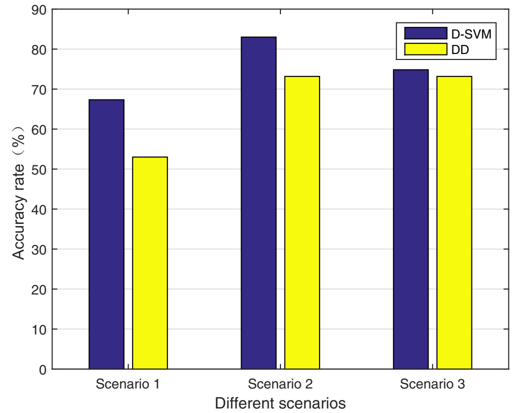

Fig. 3 Decision accuracy rate comparison between the proposed D-SVM and DD under different scenarios.

TABLE II Simulation Parameters

Parameters	Values
Lambertian index m	1.0
The physical area of PD A_p	1 cm^2
FOV semi-angle of PD Θ_F	90°
Gain of optical filter $T_s(\theta)$	1.0
Refractive index n	1.5
Optical to electric conversion efficiency γ	0.53 A/W
Transmitted optical power per LiFi AP P_t	9 W
Noise power spectral density N_0	10^{-21} A^2/Hz
Modulation bandwidth for LED lamp B	40 MHz

For a testing sample, when the predicted access type is the same as the actual optimal network access type, the SVM model achieves an accurate decision. The decision accuracy rate is the proportion of samples correctly predicted by SVM in the total testing samples, which measures the decision effect of the trained SVM model. Fig. 3 presents the comparison in terms of the decision accuracy rate between the proposed D-SVM and DD under different simulation scenarios. It can be seen that D-SVM achieves higher decision accuracy rate than DD under those three indoor scenarios, which indicates that when current blockage parameters are unknown, the user adopting D-SVM is more likely to select the network access type that attains the highest equivalent data rate.

The average equivalent data rate of users is illustrated to evaluate the performance of D-SVM. In Fig. 4, it is evident that the average equivalent data rate of users achieved by D-SVM is higher than that realized by DD under different scenarios, since D-SVM can obtain more accurate access type decisions when current blockage parameters are unknown.

Fig. 5 shows the numerical results about cumulative distribution function (CDF) of equivalent data rate per user when adopting four different network access schemes under Scenario 3. It can be seen that when users simply adopt one

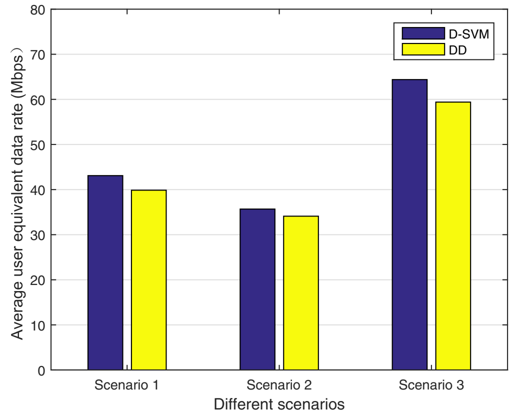

Fig. 4 Average equivalent data rate comparison between D-SVM and DD under different scenarios.

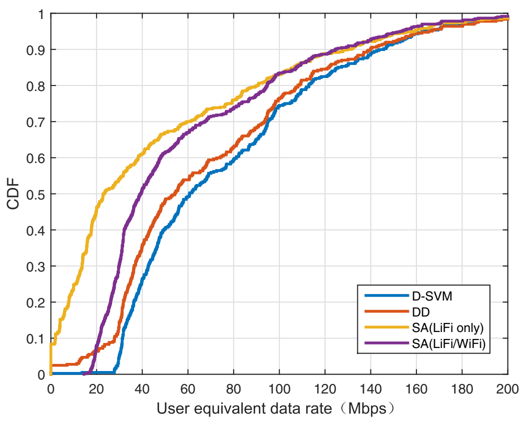

Fig. 5 CDF of equivalent data rate per user under Scenario 3 using different access schemes.

of the SA schemes, the equivalent data rate performance is worse than D-SVM, since LiFi channel blockage and frequent handover between networks lead to significantly data rate loss of the users, which adopt either "LiFi only" or "LiFi/WiFi" respectively. From Fig. 5, D-SVM is better than DD in terms of the equivalent data rate. In a word, when current blockage parameters are unknown, the proposed D-SVM is capable of dealing with the indoor obstructions effectively and providing better communication quality for users compared with three state-of-the-art benchmarks.

V. Conclusion

In this paper, the network access type decision in indoor hybrid LiFi and WiFi networks is investigated. Since real-time LiFi channel blockage parameters are unknown in a practical scenario, the traditional DD scheme may lead to non-optimal access type decision. To solve this problem, a D-SVM scheme is proposed to determine the appropriate network access type for users, which achieves higher equivalent data rate in the hybrid network. Different from both DD and SA schemes, the proposed D-SVM scheme exploits the correlation of blockage parameters between adjacent states to train a SVM decision model for better network access type decision. As demonstrated in the simulation results, the D-SVM scheme can effectively cope with the variation of channel blockage parameters caused by the movement of users or obstacles and outperform both DD and SA schemes in terms of the equivalent data rate performance.

Acknowledgement

This work was supported in part by National Natural Science Foundation of China (Grant No. 61871253), in part by Guangdong Optical Wireless Communication Engineering and Technology Center and in part by Shenzhen VLC System Key Lab (ZDSYS20140512114229398). *(Corresponding author: Zhaocheng Wang)*

References

[1] Z. Wang, Q. Wang, W. Huang, and Z. Xu, *Visible Light Communications: Modulation and Signal Processing*, Wiley-IEEE Press, 2017.

[2] H. Elgala, R. Mesleh, and H. Hass, "Indoor optical wireless communication: potential and state-of-the-art," *IEEE Commun. Mag.* vol. 49, no. 9, pp. 56-62, Sept. 2011.

[3] X. Wu, M. Safari, and H. Haas, "Joint optimisation of load balancing and handover for hybrid LiFi and WiFi networks," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, 2017, pp. 1-5.

[4] D. Basnayaka, and H. Haas, "Hybrid RF and VLC systems: Improving user data rate performance of VLC systems," in *Proc. IEEE Vehicular Technology Conference (VTC Spring)*, 2015, pp. 1-5.

[5] L. Hanzo, H. Haas, D. O'Brien, M. Rupp, and L. Gyongyosi, "Wireless myths, realities, and futures: from 3g/4g to optical and quantum wireless," *IEEE Proc.* vol. 100, no. Special Centennial Issue, pp. 1853-1888, 13 May 2012.

[6] M. Rahaim, A. Vegni, and T. Little, "A hybrid radio frequency and broadcast visible light communication system," in *Proc. IEEE GLOBECOM Workshops*, 2011, pp. 792-796.

[7] X. Wu, D. Basnayaka, M. Safari, and H. Haas, "Two-stage access point selection for hybrid VLC and RF networks," in *Proc. IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2016, pp. 1-6.

[8] A. Gupta, P. Garg, and N. Sharma, "Hybrid LiFi-WiFi indoor broadcasting system," in *Proc. IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2017, pp. 1-6.

[9] J. Hou, and D. O'Brien, "Vertical handover-decision-making algorithm using fuzzy logic for the integrated Radio-and-OW system," *IEEE Trans. Wirel. Commun.* vol. 5, no. 1, pp. 176-185, Jan. 2006.

[10] X. Wu, and H. Haas, "Access point assignment in hybrid LiFi and WiFi networks in consideration of LiFi channel blockage," in *Proc. IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, 2017, pp. 1-5.

[11] Y. Wang, and H. Haas, "Dynamic load balancing with handover in hybrid Li-Fi and Wi-Fi networks," in *Proc. IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2014, pp. 575-579.

[12] J. M. Kahn, and J. R. Barry, "Wireless infrared communications," *IEEE Proc.* vol. 85, no. 2, pp. 265-298, Feb. 1997.

[13] S. Dimitrov, and H. Haas, "Optimum signal shaping in OFDM-Based optical wireless communication systems," in *Proc. IEEE Vehicular Technology Conference (VTC Fall)*, 2012, pp. 1-5.

[14] W. Chen, J. Zhang, M. Gao, and G. Shen, "Performance improvement of 64-QAM coherent optical communication system by optimizing symbol decision boundary based on support vector machine," *Opt. Commun.* vol. 410, pp. 1-7, March 2018.

[15] G. Shi, and S. Liu, "Model selection of RBF kernel for C-SVM based on genetic algorithm and multithreading," in *Proc. IEEE International Conference on Machine Learning and Cybernetics (ICMLC)*, 2012, pp. 382-386.

[16] C. Chang, and C. Lin, LIBSVM: a library for support vector machines, 2001.

[17] H. Wang, and N. Moayeri, "Finite-state Markov channel-a useful model for radio communication channels," *IEEE Trans. Veh. Technol.* vol. 44, no. 1, pp. 163-171, Feb. 1995.