International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 03
March 2020

Access Point Selection for Hybrid Li-Fi and Wi-Fi Networks

Rahul Jaiswal*, Pavan Kumar[2]

[1] Department of ECE, Maharishi University of Information & Technology, Lucknow, India
[2] Assistant Professor ECE Departments, Maharishi University of Information & Technology, Lucknow, India
(rahul212029@gmail.com, pavandohare25@gmail.com)

***Abstract**: Hybrid light fidelity (Li-Fi) and wireless fidelity (Wi-Fi) networks are an emerging technology for future indoor wireless communications. This hybrid network combines the high-speed data transmission offered by visible light communication and the ubiquitous coverage of radio-frequency techniques. While a hybrid network can improve the system throughput and users' experience, it also challenges the process of access point selection (APS) due to the mixture of heterogeneous access points. In this paper, the differences between homogeneous and heterogeneous networks regarding APS are discussed, and a two-stage APS method is proposed for hybrid Li-Fi/Wi-Fi networks. In the first stage, a fuzzy logic system is developed to determine the users that should be connected to Wi-Fi. In the second stage, the remaining users are assigned in the environment of a homogeneous Li-Fi network. Compared with the optimisation method, the proposed method achieves a close-to-optimal throughput at significantly reduced complexity. Simulation results also show that our method greatly improves the system throughput over the conventional methods, such as the signal strength strategy and load balancing, at slightly increased complexity.*

1. Introduction

Mobile communication has been technically challenged by exponentially increasing demands for data traffic. The Cisco visual networking index (VNI) [2] reports that global mobile data traffic reached 2.5 exabytes per month at the end of 2014, which is 69% more than the traffic at the end of 2013. During the same period, the average cellular network connection speed increased by 20% only. One solution to relieve the pressure on existing base stations is offloading traffic to wireless fidelity (Wi-Fi), based on the fact that over 80% of mobile data traffic comes from indoor locations. However, the dense deployment of Wi-Fi hotspots becomes the bottleneck of improving the system capacity. An alternative short-range wireless communication technology is visible light communication (VLC) [3] and its networking variant, light fidelity (Li-Fi) [4]. In Li-Fi, light-emitting diode (LED) lamps act as access points (APs), and light is used as a medium to carry information bits via intensity modulation and direct detection (IM/DD). At the receiver, a photon diode (PD) is employed to collect photons and convert them into electric current. Unlike the radio-frequency (RF) techniques including Wi-Fi, Li-Fi does not experience interference from other sources because it is contained within a specific area, and light is not transferred through opaque objects such walls. In addition, Li-Fi offers a much wider spectrum than RF, and is licence-free. Furthermore, Li-Fi can be used in RF-restricted areas such as hospitals and underwater. Recent research shows that by using a single LED, Li-Fi is capable of offering high-speed data transmission in the Gbps range [5].

2. Literature Review

A Li-Fi AP has a smaller coverage area than Wi-Fi, of approximately 2–3 m diameter [6]. In order to provide enhanced coverage, a hybrid Li-Fi and Wi-Fi network, which combines the high-speed data transmission of Li-Fi and the relatively large coverage of Wi-Fi, is envisioned for indoor wireless communications [7]. In [8], it was shown that such a hybrid network can achieve a greater throughput than stand-alone Wi-Fi or Li-Fi networks. In that study, all of the users are first connected to the Li-Fi network, and then those of low achievable data rates are switched to Wi-Fi. This access point selection (APS) method fails to take into account the fact that the required data rates might vary with users. Also, due to the limited Wi-Fi resource, switching a Li-Fi user that achieves a low data rate to Wi-Fi does not necessarily benefit the overall network performance. An apparent example is that user

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 03
March 2020

receives a very weak Wi-Fi signal and could drain the Wi-Fi resource to meet its demand for data rate.

Motivated by this, we propose a novel APS method based on fuzzy logic for a hybrid Li-Fi and Wi-Fi network. Fuzzy logic, which was first introduced by Zadeh [13] in 1965, is an approach to computing based on "degrees of truth" rather than the usual "true or false" Boolean logic. This approach can readily handle a complicated problem by transforming it into a checklist of rules, and thus has been widely used in control.

A Li-Fi AP has a smaller coverage area than Wi-Fi, of approximately 2–3 m diameter [6]. In order to provide enhanced coverage, a hybrid Li-Fi and Wi-Fi network, which combines the high-speed data transmission of Li-Fi and the relatively large coverage of Wi-Fi, is envisioned for indoor wireless communications [7]. In [8], it was shown that such a hybrid network can achieve a greater throughput than stand-alone Wi-Fi or Li-Fi networks. In that study, all of the users are first connected to the Li-Fi network, and then those of low achievable data rates are switched to Wi-Fi. This access point selection (APS) method fails to take into account the fact that the required data rates might vary with users. Also, due to the limited Wi-Fi resource, switching a Li-Fi user that achieves a low data rate to Wi-Fi does not necessarily benefit the overall network performance. An apparent example is that user receives a very weak Wi-Fi signal and could drain the Wi-Fi resource to meet its demand for data rate.

3. System Model

A. Hybrid Li-Fi and Wi-Fi Network

Consider a generalised hybrid Li-Fi and Wi-Fi network for indoor downlink communications, where a number of rooms or compartments are taken into account, as shown in Fig. 1. Each room has a number of ceiling LED lamps, and each lamp is enabled as a Li-Fi AP covering a confined area. Also, a Wi-Fi AP is fitted in each room, providing coverage for the entire room. Though the APs might be irregularly placed in practice, we assume Li-Fi APs to be arranged in a rectangular shape and Wi-Fi APs in the room centres for the purpose of simplicity. Carrier sense multiple access with collision avoidance (CSMA/CA) is used in the Wi-Fi system [15], and therefore no interference occurs among Wi-Fi APs. Regarding the Li-Fi system, all of the Li-Fi APs reuse the same bandwidth. Since light does not penetrate walls, interference only exists between those Li-Fi APs in the same room. At each Li-Fi AP, time-division multiple access (TDMA) is adopted to serve multiple users.

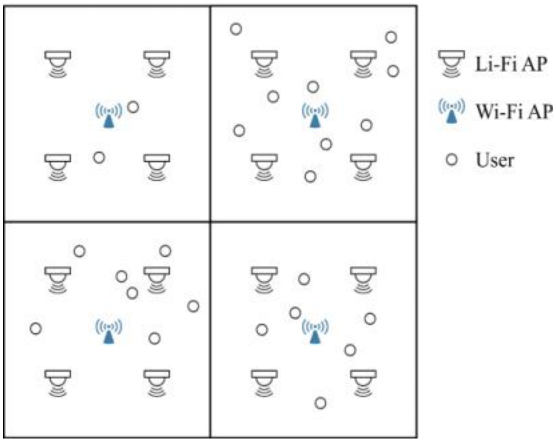

Fig. 1Schematic diagram of an indoor hybrid Li-Fi and Wi-Fi network.

B. Li-Fi Channel Model

A VLC channel is comprised of the line of sight (LOS) and non line of sight (NLOS) paths. The geometry of indoor VLC propagation is presented in Fig. 2. It is assumed that each user device is fitted with a PD vertically facing upwards. The LOS path of Li-Fi AP i and user u is the straight line between them, and the corresponding Euclidean distance is denoted by $d_{i,u}$. The angles of irradiance and incidence related to the LOS path are denoted by □i,u and $\psi_{i,u}$, respectively. The LOS channel of Li-Fi is formulated as [16, eq. (10)]:

$$H_{\mathrm{LOS}}^{i,u} = \frac{(m+1)A_{\mathrm{pd}}}{2\pi d_{i,u}^2}\cos^m(\phi_{i,u})g_f g_c(\psi_{i,u})\cos(\psi_{i,u}),$$

where $m=-\ln 2/\ln(\cos\Phi_{1/2})$ is the Lambertian emission order, and $\Phi_{1/2}$ is the radiation angle at which the intensity is half of the intensity at the main-beam direction; A_{pd} denotes the physical area of PD; g_f is the gain of the optical filter; and $g_c(\psi_{i,u})$ is the optical concentrator gain, which is given by:

$$g_c(\psi_{i,u}) = \begin{cases} \dfrac{n^2}{\sin^2(\Psi_{\max})}, & 0 \le \psi_{i,u} \le \Psi_{\max} \\ 0, & \psi_{i,u} > \Psi_{\max}, \end{cases}$$

where n denotes the refractive index, and Ψ_{max} is the semi-angle of the field of view (FOV) of the PD.

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 07 Issue 03
March 2020

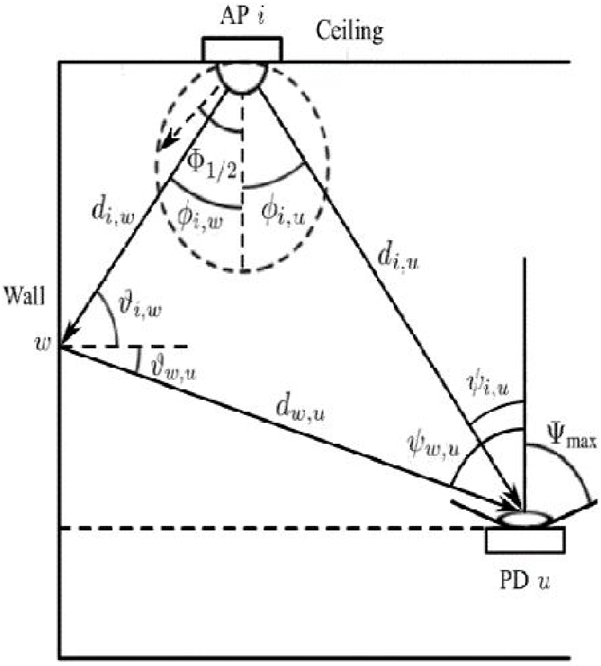

Fig. 2. Geometry of indoor VLC downlink propagation

For the NLOS path, only first-order reflections are taken into account for the purpose of simplicity. A first-order reflection consists of two segments: i) from the AP to a small area w on the wall; and ii) from w to the user. The Euclidean distances of those segments are denoted by $d_{i,w}$ and $d_{w,u}$, respectively.

C. Wi-Fi Channel Model

The path loss model used for indoor RF propagation consists of the free space loss (slope of 2) up to a breakpoint distance, and a slope of 3.5 after the breakpoint distance [17]. Let $L_{FS}(\cdot)$, X_σ and d_{BP} denote the free space loss, the shadow fading and the breakpoint distance, respectively. The path loss is written as

$$L(d) = \begin{cases} L_{FS}(d) + X_\sigma, & d \le d_{BP} \\ L_{FS}(d) + 35\log_{10}\left(\frac{d}{d_{BP}}\right) + X_\sigma, & d > d_{BP}, \end{cases}$$

4. Conventional Access Poin Selection Methods

The SSS is a straightforward method that always selects the AP offering the highest spectrum efficiency. In a homogeneous network, the receiver experiences the same level of noise power when collecting the signals emitted from different APs. Therefore for the user of interest, the SSS method simply selects the AP that delivers the highest received signal power. In a hybrid network, however, different mechanisms are needed to receive light and radio signals, leading to different noise power per bandwidth between the Li-Fi and Wi-Fi systems. Also, those two systems could use different bandwidths. Thus we adopt signal-to-noise ratio (SNR) instead of signal strength to perform the SSS method in a hybrid network. With AP i sending out the desired signal, the received SNR at user u is denoted by $\gamma_{i,u}$:

$$\gamma_{i,u} = \begin{cases} \frac{(R_{pd} H^{i,u}_{\text{Li-Fi}} P_{opt}/\kappa)^2}{\mathcal{N}_{\text{Li-Fi}} B_{\text{Li-Fi}}}, & \text{if i is a Li-Fi AP} \\ \frac{G^{i,u}_{\text{Wi-Fi}} P_{\text{Wi-Fi}}}{\mathcal{N}_{\text{Wi-Fi}} B_{\text{Wi-Fi}}}, & \text{if i is a Wi-Fi AP.} \end{cases}$$

B. Load Balancing

The LB methods, which consider resource availability as well as channel quality, can be classified into two categories: channel borrowing and traffic transfer. Since Li-Fi and Wi-Fi operate at different spectrum, channel borrowing is infeasible in a hybrid Li-Fi/Wi-Fi network. Here we consider a straightforward traffic-transfer method, while the optimisation-based LB is deemed as an optimisation method.

Using this LB method, the user is connected to the AP offering the highest SNR if that AP can meet the user's data rate requirement. Otherwise, the user selects the AP that provides the highest user's satisfaction. Note that this AP could still be the one offering the highest SNR. If several APs achieve the highest user's satisfaction, the one having the highest SNR is chosen. In other words, the LB method first maximises the user's satisfaction, and then maximises the channel quality. The corresponding OF is expressed as:

$$\begin{aligned} &\text{maximise } \gamma_{i,u} \\ &\text{subject to } i \in \max\{S_{i,u} | i \in \boldsymbol{L}_u \cup \boldsymbol{W}\}. \end{aligned}$$

Optimisation Method

The most commonly used optimisation method is max-sum-log-rate wise

$$\Gamma(\alpha) = \sum_{u \in \boldsymbol{U}} \sum_{i \in \boldsymbol{L}_u \cup \boldsymbol{W}} \alpha_{i,u} \log(\tau_{i,u} \eta_{i,u} B_i),$$

where $\alpha_{i,u}$ is a binary value that indicates the connection status: $\alpha_{i,u}=1$ means user u is connected to AP i, and $\alpha_{i,u}=0$ means otherwise. The elements of $\alpha_{i,u}$ for all pairs of AP and user constitute the matrix α , which is a possible solution to the APS for all involved users.

Proposed Access Point Selection Method

In this section, based on the different characteristics between Li-Fi and Wi-Fi in terms of coverage and capacity, we propose a tailor-made APS method for the hybrid network. The main contribution of this section is three-fold: i) analyse the key issues when conducting the conventional APS methods in a hybrid network; ii) formulate the APS process as a two-stage problem, which firstly determines the users that need service from Wi-Fi and then performs APS for the remaining users as if in a homogeneous Li-Fi network; and iii) apply fuzzy logic to the first stage to rank the user's priority of accessing Wi-Fi. Regarding the second stage, a conventional APS method, such as the SSS and LB, is applicable.

A. Discussion About the APS in a Hybrid Network

With respect to APS, a hybrid network differs from a homogeneous network in two aspects: i) the coverage areas of different systems overlay one another; and ii) the coverage range varies with the AP types. The first point widens the scale of possible options for APS, leading to an exponential increase in the computational complexity required by the optimisation method. See the complexity analysis in Section V-B. Regarding the second point, a Wi-Fi AP has a larger coverage area but less capacity than a Li-Fi AP. In Fig. 3, the Wi-Fi SNR is stronger than the Li-Fi SNR in the green area, which covers 32% of the room, while otherwise in the red area. Considering uniformly distributed users, this means the Wi-Fi AP has to serve 32% users if the SSS is adopted. Meanwhile, in average, each Li-Fi AP serves less than 6% users. Therefore in this situation the Wi-Fi system is prone to be overloaded, i.e., it cannot meet the data rate demands of all served users. Also, it is worth noting the users nearby a Wi-Fi AP are attracted to Wi-Fi, even if they are right beneath a Li-Fi AP (e.g., user 1). As a result, the Li-Fi APs close to a Wi-Fi AP are underused. The LB method can relieve the congestion of Wi-Fi by diverting new users to Li-Fi. However, because of not affecting the AP assignment of existing users, the LB method does not necessarily improve the usage of those underused Li-Fi APs. The lack of efficiency in Li-Fi raises an open question: assigning what kind of users to Wi-Fi (or Li-Fi) is beneficial to the entire hybrid network?

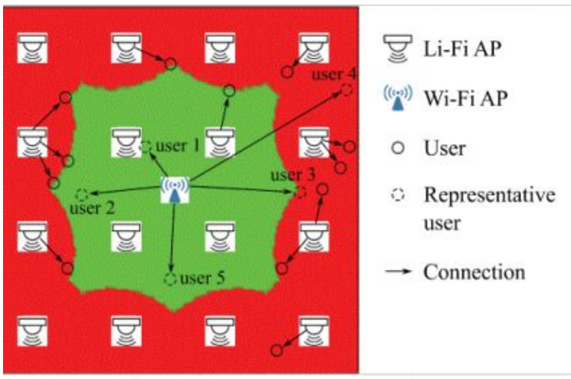

Fig. 3. Representative users for APS in a hybrid Li-Fi and Wi-Fi network.

Fig. 3 demonstrates some representative users. Due to the presence of ICI in the Li-Fi network, cell-centre users (e.g., user 1) obtain a much higher SINR and thus a much higher spectrum efficiency than cell-edge users (e.g., user 2). Note that both user 1 and 2 would be connected to Wi-Fi if the SSS is applied. To reach the same data rate, user 2 requires more resource than user 1 if they are both switched to Li-Fi. Hence assigning user 2 to Wi-Fi is better than assigning user 1, though user 1 receives a stronger Wi-Fi signal than user 2 does. User 3 is in a situation similar to user 2, but locates in the field where the Wi-Fi SNR is lower than the Li-Fi SNR. In other words, user 3 is connected to Li-Fi when using the SSS method. Because of receiving a lower Wi-Fi SNR, user 3 has a lower priority than user 2 to use the Wi-Fi resource.

B. Proposed APS Method

The APS for a hybrid Li-Fi and Wi-Fi network is formulated as a two-stage problem: i) determine the users that need to be served by Wi-Fi ; and ii) conduct APS for the remaining users as if they are in a stand-alone Li-Fi network. We apply fuzzy logic (FL) to fulfil the task of the first stage, while the SSS or LB can be used in the second stage. Correspondingly, the formed methods are referred to as the FL-SSS and FL-LB. In the following context, a FL system is developed to measure how well a user should be assigned to Wi-Fi.

5. Simulation Results

In this section, Monte Carlo simulations are conducted to validate the performance of the proposed method in comparison with the conventional methods. Consider an indoor scenario with 4 rooms as shown in Fig. 1, and each room is square with a side length of 10 m. On the ceiling of each room, 16 Li-Fi APs are placed in a layout of a square matrix, with a separation of 2.5 m between the closest two. The users are randomly distributed with a uniform probability distribution. In addition, the number of available Wi-Fi channels is assumed equal to the number of Wi-Fi APs, except when analysing its effects on the network performance.

Performance Comparison

Fig. 3 presents the users' satisfaction and fairness of various methods when the average required data rate is 10 Mbps. As shown in Fig. 9(a), the proposed method can significantly increase the users' satisfaction over the SSS and LB, especially for a large number of users. When 30 users are present, using the SSS can meet the data requirements for only 74.6% of the users. This value is increased to 87.4% by employing the LB instead of the SSS. When using the FL-SSS and FL-LB, the proportion of satisfied users is 96.1% and 91.9%, respectively. Note that there is a cross point between the curves of the FL-SSS and FL-LB. This is because using the LB in the proposed method can improve the performance of deeply-unsatisfied users, by decreasing the number of satisfied users. In Fig. 9(b), the fairness among users is shown for different numbers of users. Two outcomes are observed: i) the fairness of all methods equals 1 given a small number of users, e.g., Nu=10 ; ii) as the number of users increases, the fairness decreases for all methods, but the fairness of the FL-LB decreases much slower than that of the other methods. At Nu=100 , the fairness of the FL-LB achieves 0.95, while the remaining methods have a fairness below 0.9.

5.1. Conclusion

In this paper, a two-stage APS method was proposed for hybrid Li-Fi and Wi-Fi networks, by exploiting the distinguishing characteristics between those two networks. The proposed method at first determines the users that need service from Wi-Fi, and then assigns the remaining users as if in a homogeneous Li-Fi network. The concept of fuzzy logic is applied in the first stage to rank the user's priority of accessing Wi-Fi. In the second stage the SSS or LB can be employed, and the proposed method is named the FL-SSS or FL-LB correspondingly. Based on experimental results and complexity analysis, it is shown that compared to the optimisation method, the proposed method achieves a near-optimal throughput at significantly reduced complexity. In addition, the FL-LB marginally outperforms the FL-SSS with a slight increase in complexity. Compared with the SSS and LB, results show that FL-LB can improve the network throughput by 24% and 11%, respectively. Future research will involve cellular network in the context of a hybrid network.

References

1. X. Wu, D. Basnayaka, M. Safari, H. Haas, "Two-stage access point selection for hybrid VLC and RF networks", *Proc. IEEE 27th Annu. Int. Symp. Pers. Indoor Mobile Radio Commun. (PIMRC)*, pp. 1-6, Sep. 2016.
2. Cisco visual networking index: Global mobile data traffic fore-cast update 2015–2020", Feb. 2016.
3. H. Burchardt, N. Serafimovski, D. Tsonev, S. Videv, H. Haas, "VLC: Beyond point-to-point communication", *IEEE Commun. Mag.*, vol. 52, no. 7, pp. 98-105, Jul. 2014
4. H. Haas, L. Yin, Y. Wang, C. Chen, "What is LiFi?", *J. Lightw. Technol.*, vol. 34, no. 6, pp. 1533-1544, Mar. 2016..
5. D. Tsonev et al., " A 3-Gb/s single-LED OFDM-based wireless VLC link using a gallium nitride \$mu \$ LED ", *IEEE Photon. Technol. Lett.*, vol. 26, no. 7, pp. 637-640, Apr. 2014.G
6. H. Haas, "Visible light communication", *Proc. Opt. Fiber Commun. Conf. Exhib. (OFC)*, pp. 1-72, Mar.
7. M. B. Rahaim, A. M. Vegni, T. D. C. Little, "A hybrid radio frequency and broadcast visible light communication system", *Proc. IEEE GLOBECOM Workshops*, pp. 792-796, Dec.
8. D. A. Basnayaka, H. Haas, "Hybrid RF and VLC systems: Improving user data rate performance of VLC Systems", *Proc. IEEE 81st Veh. Technol. Conf. (VTC Spring)*, pp. 1-5, May 2015.
9. K. Son, S. Chong, G. Veciana, "Dynamic association for load balancing and interference avoidance in multi-cell networks", *IEEE Trans. Wireless Commun.*, vol. 8, no. 7, pp. 3566-3576, Jul. 2009.
10. Y. Bejerano, S. J. Han, L. Li, "Fairness and load balancing in wireless LANs using association control", *IEEE/ACM Trans. Netw.*, vol. 15, no. 3, pp. 560-573, Jun. 2007.
11. Y. Wang, X. Wu, H. Haas, "Distributed load balancing for Internet of Things by using Li-Fi and RF hybrid network", *Proc. IEEE 26th Annu. Int. Symp. Pers. Indoor Mobile Radio Commun. (PIMRC)*, pp. 1289-1294, Aug./Sep. 2015.
12. X. Li, R. Zhang, L. Hanzo, "Cooperative balancing in hybrid light communications and WiFi", *IEEE Trans. Commun.*, vol. 63, no. 4, pp. 1319-1329, 2005