Efficient Resource Allocation Scheme in Multi-User LiFi Networks Based on Angle Oriented Transceiver

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***Abstract*—In this paper, an efficient resource allocation scheme in multi-user LiFi networks is proposed using the angle oriented (AO) technology at the receiver and transmitter sides. To cope with the inter-symbol and inter-user interferences and to further enhance the fairness between the users, we efficiently allocate the resources by choosing the most suitable LED for each AO transmitter (i.e., user) to be ON. The none-selected LEDs are switched OFF to maximize the received signal-to-interference-plus-noise-ratios (SINRs). The resource allocation problem under consideration is a discrete non-convex one with multi-objective optimizations. To obtain the optimal solution, the exhaustive-search (ES) method is used while to reduce the complexity, a sub-optimal method is proposed using genetic algorithm (GA) scheme. Our results confirm the accuracy of the proposed sub-optimal solution where less than 0.5 dB difference in the SINR value is noticed. Also, the proposed LiFi system with AO technology shows a superior performance compared to the conventional systems with single transmitter (ST) scheme.**

I. Introduction

Light fidelity (LiFi) communication technology has been captured much interest to be considered in 5G/6G indoor wireless communication applications [1], [2]. Such technology can be designed by utilizing visible light (VL) and/or infrared (IR) spectrum. Usually, VL-LED is used to offload the downlink traffic [3] while the near-IR-LED can be deployed in the uplink one [4], [5] to achieve the full-duplex wireless connectivity.

LiFi systems provide high data rate and power efficient communication networks when single-user scenarios are considered. In multi-user scenarios, however, the resulting inter-symbol interferences (ISI) and inter-user interferences (IUI) degrade the system performance and limit the achievable data rates. To reduce the ISI resulting from the multi-path reflections, the angle oriented (AO) receiver can be used [6], [7]. The AO receiver (AORx) consists of multiple photodetectors (PDs) oriented in different directions with different normal unit vectors and incident angles. As a result, the correlation in the channel gain matrix between the transmitters and PDs is much reduced particularly when the field-of-view angle of these PDs is optimized as in [8], [9].

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To tackle with IUI problem, multiple access and/or resource allocation schemes were used, see the survey in [10], [11] and the references therein. The high peak-to-average-power-ratio, and longer delays were their limitations. Recently, in [12], a new resource allocation scheme based on AO technology has been proposed. However, the time complexity was a bottleneck as it mainly depends on the exhaustive search (ES) method to assign the resources.

In this paper, we propose an efficient resource allocation scheme in multi-user uplink LiFi system utilizing the AO technology. Multiple AO receivers (AORx) and AO transmitters (AOTx) are used at the Rx and Tx sides, respectively. To cope with ISI and IUI problems, and to enhance the fairness between the users, we efficiently allocate the resources by choosing most suitable LED per user (i.e., AOTx) to be ON. The none-selected LEDs are switched OFF to maximize the received signal-to-interference-plus-noise-ratios (SINRs). The formulated resource allocation problem is discrete non-convex optimization one with multi-objective optimizations. To obtain the optimal solution, the ES method is used while to reduce the complexity, a sub-optimal fair resource allocation (SFRA) method is proposed using genetic algorithm (GA) scheme. The results reveal that the proposed SFRA has a very good match with the optimal solution.

II. System and Channel Model

We consider the uplink Multi-user LiFi system indicated in Fig. 1. We have U users, each uses an AOTx with L IR-LEDs to send his/her data. On the other side, a number of R AORx are used to receive the data, each has P PDs. The channel gain for the link between the l^{th} LED and p^{th} PD is the sum of line of sight (LoS) and non-LoS (NLoS) gains which are given respectively as the following:

$$h_{lp}^{los} = \begin{cases} \dfrac{(m_l+1)A\cos^{m_l}(\theta_{lp})\cos(\phi_{lp})}{2\pi(d_{lp})^2} G(\phi_{lp}), \phi_{lp} \leq \psi, \\ 0, \qquad \phi_{lp} > \psi \end{cases} \tag{1}$$

and

$$dh_{lpk}^{nlos} = \begin{cases} \dfrac{(m_l+1)\rho A\cos^{m_l}(\theta_{lpk})\cos(\alpha_{lpk})\cos(\beta_{lpk})\cos(\phi_{lpk})}{2\pi^2 d_{lk}^2 d_{kp}^2} \\ \times G(\phi_{lpk}) dA_k, \qquad \phi_{lpk} \leq \psi, \\ 0, \qquad \phi_{lpk} > \psi \end{cases} \tag{2}$$

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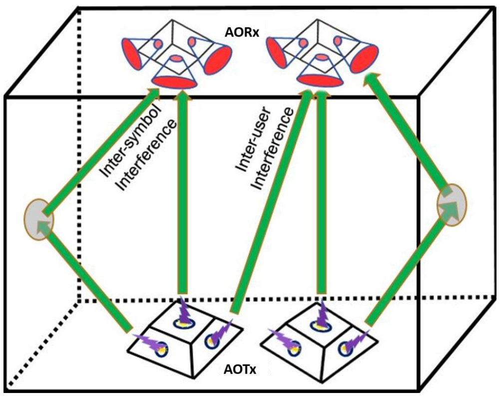


Fig. 1. Multi-user LiFi system deploying the angle oriented technology at the transmitter and receiver sides.

where A is the PD's area and m_l represents the Lambertian order of the LED transmitter. θ, ϕ and d are the angle of irradiance, the angle of incidence, and the propagation distance between the LED and the PD, respectively. In (1), (2), $G(\phi)$ and dA_k denote the gain of optical concentrator and the area of the k^{th} reflecting element, respectively.

III. Proposed Resource Allocation Scheme in Multi-User LiFi Networks

As indicated in Fig. 1, the LiFi system under consideration has a dimension of $(U \times L \times R \times P)$. To decrease the dimensions of the optimization problem and reduce the transmitted power amount of each Tx, we choose only one of the AOTx' LEDs to be ON at a time while the remaining other LEDs are switched OFF. Each active LED transmits an average optical power of P_t. The allocation matrix which defines the operating LED for each user is made to maximize the SINR of each user u, Γ_u. At an allocation matrix A, we can define a vector $\hat{a} = [a_1^*, a_2^*, \cdots, a_U^*]$ which represents the index of the operating LED for each user, i.e., $a_u^* \in [1, \cdots, L]$ denotes the index of ON LED of u^{th} user at the allocation vector of $\hat{a}$. The SINR between the u^{th} user and p^{th} PD, $\Gamma_{pu}(\bar{a})$ including both IUI and ISI is calculated by [12]

$$\Gamma_{up}(\bar{a}) = \frac{(\sum_{l=1}^{L} \eta P_t a_{ul} H_{pul}^{los})^2}{\sigma_n^2 + \sum_{j=1, j\neq u}^{U} (\sum_{l=1}^{L} \eta P_t a_{jl} H_{pjl}^{los})^2 + \sum_{j=1}^{U} (\sum_{l=1}^{L} \eta P_t a_{jl} H_{pjl}^{nlos})^2} \tag{3}$$

where η and σ_n^2 denote the PD responsivity and system noise variance, respectively. Firstly, for an allocation vector $\bar{a}$, the PD p is assigned to the u^{th} user that has highest $\Gamma_{up}(\bar{a})$ using assignment variable $U_p(\bar{a})$ given as:

$$U_p(\bar{a}) = \arg \max_{u \in \{1,2,\cdots,U\}} \Gamma_{pu}(\bar{a}), \ \forall p \in \{1, 2, \cdots, (P \times R)\}. \tag{4}$$

The received SINR of user u at a given allocation vector $\bar{a}$ can be therefore given by

$$\Gamma_u(\bar{a}) = \begin{cases} \max\limits_{p \in (P\times R)} \gamma_{pu}(\bar{a}), \forall p \colon u = U_p(\bar{a}) \\ 0, \qquad \forall p \colon u \neq U_p(\bar{a}) \end{cases} \quad \forall u \in \{1, 2, \cdots, U\} \tag{5}$$

Algorithm 1 Proposed Sub-optimal Fair-Resource-Allocation (SFRA) Algorithm

Inputs:
  R, U, P, L
Set maximum iterations T_{max}
Set the index of the iteration $T = 0$
Generate the initial random solution for $\bar{a}$
repeat
for $p = 1$ to $R \times P$ **do**
  for $u = 1$ to U **do**
    for $l = 1$ to L **do**
Obtain (3) from the pilot signals
Update $\bar{a}$ with constraint $1 \leq a_u^* \leq L$
Solve problem (6) obtaining $\bar{a}_{opt}$
$T \leftarrow T + 1$;
    end for
  end for
end for
until convergence to optimal solution or $T > T_{max}$

After that, the objective is to determine the allocation matrix A in a way that maximizes the SINR of each user u. Obviously, there are different feasible allocation matrices that achieve this constraint. From these matrices, there is a one that achieves the highest fairness between all users. Therefore, the problem under consideration is formulated as a max-min optimization problem as

$$\begin{aligned} & \max_{\hat{a}} \min_{u} \Gamma_u(\hat{a}) \\ & s.t. \\ & a_{ul} = \{^{1,\, l = a_u^*}_{0,\, otherwise}, \forall u, l \\ & \textstyle\sum_{l=1}^{L} a_{ul} = 1, \forall u \\ & P_{ul} = P_t, \forall u, l \\ & u \in \{1, 2, \cdots, U\}, \ l \in \{1, 2, \cdots, L\}, \\ & p \in \{1, 2, \cdots, (P \times R)\}, \ a_u^* \in \{1, 2, \cdots, L\} . \end{aligned} \tag{6}$$

To obtain the optimal solution for this problem, we use the ES method while to reduce the complexity, a sub-optimal fair-resource-allocation (SFRA) solution is proposed deploying the genetic algorithm (GA) scheme as shown as Algorithm 1.

IV. Performance Results and Discussion

To compare the results of the two methods and investigate the system performance, we consider two scenarios of user distribution, i.e., Sc 1 and Sc 2 in a room with dimensions of 5 m × 5 m × 3 m as indicated in Fig. 2. Each AORx and AOTx has five PDs and five LEDs, respectively. We assume the total transmit power of each AOTx is 1 W, i.e., $P_t = 1$ and each PD has a responsivity of η = 0.53 A/W. All simulation parameters are included in Table. I. In Fig. 3(a), we present the SINR results obtained from the proposed SFRA method and the optimal results obtained using ES method. It is observed from Fig. 3(a) that proposed sub-optimal solution (GA) has a very good match with the optimal solution, only a very small difference less than 0.5 dB is existing.

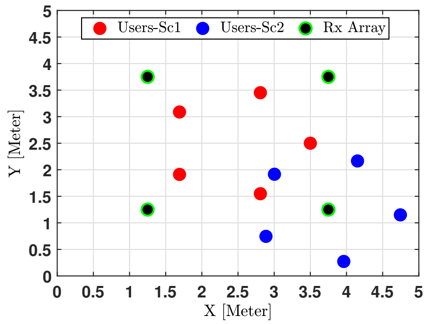


Fig. 2. Multi-user LiFi scenarios under consideration.

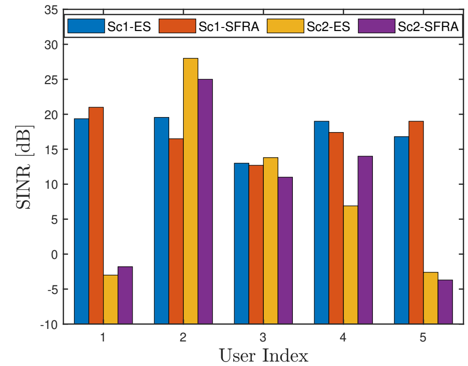
TABLE I
SIMULATION PARAMETERS

Parameters	Values
Room size	5 m × 5 m × 3 m
Reflection ratio (ρ)	0.7
Reflective element area (dA)	1 cm^2
AOTx height	1 m
Number of users (U)	5
Number of LEDs/user (L)	5
Power per LED (P_t)	1 w
Number of AORx (R)	4
Number of PDs/AORx (P)	5
PD Responsivity (η)	0.53 A/W
PD Area (A)	1 cm^2
System bandwidth	25 MHz

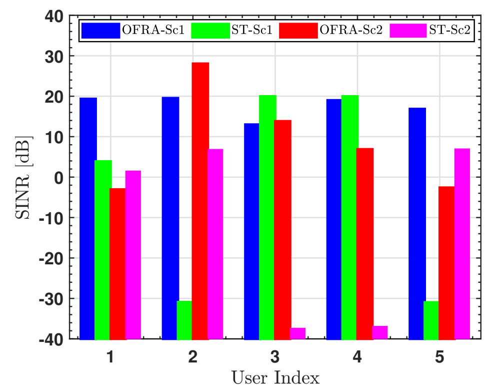
In Fig. 3(b), we compare the obtained results using proposed SFRA scheme using the AO technology with the results obtained using the conventional ST scheme. It is obvious that proposed SFRA scheme has a superior performance comparing with ST one. It is obvious in ST scheme a significant SINR reduction for some users (2^{nd} and 5^{th} users in Sc1 and 3^{rd} and 4^{th} users in Sc2) due to the increased interference levels.

V. CONCLUSION

In this work, we first investigated the performance of multi-user LiFi systems when a ST is used for each user. The resultant SINR performance was significantly degraded due to the effect of both ISI and IUI. Therefore, we utilized the AO technology at both the Tx and Rx sides in order to reduce such interference effect. We further proposed a new resource allocation scheme named SFRA in the uplink multi-user LiFi system to improve the fairness and the reliability of the uplink channel. A sup-optimal solution has been proposed based on the GA which has been compared with the optimal solution obtained via the ES method. The results revealed that the proposed SFRA is in a good agreement with the optimal one avoiding the complexity of the ES method. Results demonstrated also that proposed SFRA scheme outperforms the conventional ST one achieving the highest fairness between the users. In order to further increase the data rate, more LEDs per user can be used which increases the optimization problem dimensions to be considered as a future work.



(a)



(b)

Fig. 3. Performance results (a) Comparison between ES and proposed SFRA methods (b) Comparison between proposed LiFi system with AO technology and the conventional ST one.

REFERENCES

[1] H. Haas *et al.*, "Introduction to indoor networking concepts and challenges in LiFi," *J. Opt. Commun. Netw.*, vol. 12, no. 2, pp. A190–A203, 2020.

[2] M. Z. Chowdhury *et al.*, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE OJ-COMS*, vol. 1, pp. 957–975, 2020.

[3] H. B. Eldeeb *et al.*, "Co-channel interference cancellation using constraint field of view ADR in VLC channel," in *IEEE Photon. Conf. (IPC)*. IEEE, 2017, pp. 1–2.

[4] M. T. Alresheedi *et al.*, "Uplink design in VLC systems with IR sources and beam steering," *IET Commun.*, vol. 11, no. 3, pp. 311–317, 2017.

[5] H. B. Eldeeb *et al.*, "Channel modelling for light communications: Validation of ray tracing by measurements," in *12th IEEE IET Int. Symposium on Commun. Systems, Networks Digital Sign. (CSNDSP)*. IEEE, 2020.

[6] A. Nuwanpriya *et al.*, "Angle diversity receiver for indoor MIMO visible light communications," in *IEEE GC Wkshps*. IEEE, 2014, pp. 444–449.

[7] Z. Zeng *et al.*, "Angle diversity receiver in LiFi cellular networks," in *IEEE Int. Conf. Commun. (ICC)*. IEEE, 2019, pp. 1–6.

[8] C. Chen *et al.*, "Reduction of SINR fluctuation in indoor multi-cell VLC systems using optimized angle diversity receiver," *J. Lightw. Technol.*, vol. 36, no. 17, pp. 3603–3610, 2018.

[9] H. B. Eldeeb *et al.*, "Interference mitigation and capacity enhancement using constraint field of view ADR in downlink VLC channel," *IET Commun.*, vol. 12, no. 16, pp. 1968–1978, 2018.

[10] M. a. Obeed, "On optimizing VLC networks for downlink multi-user transmission: A survey," *IEEE Commun. Surveys & Tuts.*, vol. 21, no. 3, pp. 2947–2976, 2019.

[11] X. Wu *et al.*, "Hybrid LiFi and WiFi networks: A survey," *arXiv preprint arXiv:2001.04840*, 2020.

[12] H. B. Eldeeb *et al.*, "Efficient resource allocation scheme for multi-user hybrid VLC/IR networks," in *IEEE Photon. Conf. (IPC)*. IEEE, 2019.