Heterogeneous AP Selection for Hybrid Li-Fi using Mathematical EGT

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Abstract:
Hybrid network combines the high-speed data transmission offered by visible light communication (VLC) and the ubiquitous coverage of radio-frequency (RF) 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 (APs). Combining the high-speed data transmission of Li-Fi and the ubiquitous coverage of Wi-Fi, hybrid Li-Fi and Wi-Fi networks (HLW Nets) are able to improve the system capacity of indoor wireless communications. Meanwhile, the process of access point (AP) selection becomes challenging, since the coverage areas of different networks completely overlap each other. In this paper, APS scheme based on mathematical approach is proposed for the Li-Fi network using ADRs. The performance of the proposed scheme is comprehensively analyzed and compared with the APS scheme based on signal strength strategy. Our result shows that the performance gap will increase as the number of users and the required data rate increase. The MRC scheme using the pro-posed sub-optimum weights achieves similar performance to the MRC scheme using the optimum weights and out performs all the other schemes.

Keywords: VLC, RF, Access point Selection, mathematical approach.

I. INTRODUCTION

Due to the increasing demand for wireless data, what is anticipated to reach 49 exabytes by 2021[1], the radiofrequency (RF) spectrum has become a very limited resource. To support the growth in data traffic and next-generation high-speed wireless communication systems, Light-Fidelity (Li-Fi) has been introduced as a new wireless access technology. The overall licence-free bandwidth of visible light is more than 1,000 times greater than the entire RF spectrum. Li-Fi can provide enhanced security as light does not penetrate through opaque objects [2]. A typical Li-Fi system uses off-the-shelf low-cost light emitting diodes (LEDs) and photodiodes (PDs) as front end devices [3]. In many large indoor environments, multiple light fixtures are installed, and these luminaries can act as VLC access points (APs). A network consisting of multiple VLCAPs is referred to as a LiFi at cellnet work[4]. Li-Fi can provide bidirectional and high-speed data communication and enhance physical layer security [5]. These features of Li-Fi have made it a topic of increased recent research. In comparison with RF femtocell networks, Li-Fi at to cell networks limits the system performance. This is because in current systems the signal transmitted to a user will interfere with other users who are receiving signals encoded in the same optical spectrum resource. In this case, cell-edge users in particular suffer from severe CCI. Despite the dense deployment of APs, due to CCI, Li-Fi may not provide uniform coverage with respect to data rate. An angle diversity receiver (ADR) consists of multiple narrow field of view (FOV) PDs facing in different directions. In [7]–[9], the ADR is used to address the CCI issue as well as the signal to interference plus noise ratio (SINR) fluctuation in Li-Fi systems, and various signal combining schemes are studied. The AP selection (APS) is important as it determines the combining weights of different combing schemes. However, in these studies, the AP selections are all based on the signal strength strategy (SSS) and only the SINR metric is investigated. In a conventional single PD receiver system suffering CCI if a user equipment (UE) is allocated to an AP other than the AP providing the best received signal strength, then the AP providing the best signal strength will become the interfering AP.

This will cause the signal power to be less than the interference power and the SINR to be less than 0 dB. In other words, only the AP with the best signal strength can provide data to the UE. Hence, the sensible and practical APS in Li-Fi systems with a single PD receiver is the SSS scheme. However, the situation is different for a LiFi system with ADRs as ADRs can greatly reduce CCI. APS has been studied for LiFi/WiFi hybrid networks in [10], [11]. In [10], the evolutionary game theory (EGT) based load balancing (LB) scheme is adopted, however, the APS scheme in the stand-alone Li-Fi system is still SSS. The EGT-based LB is only used to select between the best Li-Fi and WiFi APs. In this study, we will propose an EGT-based APS scheme considering handover for the stand-alone Li-Fi system using ADRs. In the EGT-based APS, each user takes individual decisions on the APS by maximizing their own quality of service (QoS) and the APS strategy will be adapted iteratively until no user can achieve a better QoS in the network. The SSS-based APS scheme and the single PD receiver will be used as the benchmark. QoS and average user data rate are the performance metrics, which is discussed in the below session.
II. SYSTEM MODEL

A. Channel Gain

In this study, an indoor LiFi network is considered, where NLiFi APs are deployed. The set of LiFi APs is denoted by A={a|a∈[1,Nl]}.

The set of users is denoted as U={μ|μ∈[1,NUE]}.

The set of users allocated to the APa is denoted as Ua and the number of users served by this APa is Ma. Each LiFi AP is composed of several low power LEDs for signal emission, and the total optical power of each LiFi AP is denoted by Ptx. In terms of the receiving device, instead of a single PD receiver, an angle diversity receiver with multiple PDs is used. The set of PDs on an ADR is denoted as P={p|p∈[1,NPD]}.

According to [12], the LiFi channel impulse response between a-th AP and p-th PD for user μ in the frequency domain is given by:

\[ H_{a,μ,p}(f) = H_{LOS}H_{F}(f), \]

where HLOS is the path loss of the line-of-sight (LOS) channel and HF(f) is the front-end device frequency response. The LOS channel fading gain between the transmitter (Tx) and receiver (Rx) can be modeled as [13]

\[ H_{LOS} = \frac{(m + 1)A_p n^3_{ref}}{2\pi d^2} \sum_{k}\frac{\omega_k}{\sum_{m}\cos\left(\frac{\varphi}{2}\right)} \cos\left(\frac{\varphi}{2}\right) \cos\left(\frac{\varphi}{2}\right) \cos\left(\frac{\varphi}{2}\right) \cos\left(\frac{\varphi}{2}\right), \]

where Ap is the physical area of the PD; m is the Lambert an order which is given as m=\ln (2)/\ln (\cos (\Phi/2)) with \Phi/2 denoting the half-power semi-angle of the LED; represents the distance between the AP and the receiver; nref denotes the internal refractive index of the concentrator and \Psi denotes the field of view of the PD; \varphi is the irradiance angle of the transmitter; \psi is the incidence angle of the receiving PD; Ts is the gain of the optical filter; Rx, Tx is the visibility factor, which is equal to one if both the transmitter and receiver are visible to each other, and it is equal to zero if not. In other words, \psi Rx,Tx=0 if \psi Rx,Tx≠0.

B. ADR

In this study, we consider the truncated pyramid receiver (TPR) proposed in [9] which is especially suitable for hand-held devices. The TPR is composed of a ring of NPD−1 inclined side PDs equally separated around the NPD-th central PD. The side PDs are arranged uniformly in a circle on the horizontal plane. In terms of the normal vector of each PD, it is characterized by two angles: the azimuth angle of a PD, \omega PD, and the elevation angle of a PD, \theta PD, which is the angle between the normal vector of the PD, nPD, and the UE, NUE. In terms of the NPD−1 side PDs on a TPR, they have identical elevation angles denoted as \Theta PD. Hence, the elevation angles can be expressed as:

\[ \Theta_{PD} = \left\{ \begin{array}{ll}
\theta_{PD} & 1 \leq p \leq N_{PD} - 1, \\
0 & p = N_{PD}.
\end{array} \right. \]

The azimuth angle of the p-th PD is denoted as [9]:

\[ \omega_{PD} = \left\{ \begin{array}{ll}
\frac{2(p-1)\pi}{N_{PD}}, & 1 \leq p \leq N_{PD} - 1, \\
0, & p = N_{PD}.
\end{array} \right. \]

Hence, the normal vector of the p-th PD is obtained as [15]:

\[ n_{PD} = [\sin(\omega_{PD}) \cos(\Theta_{PD}) \sin(\omega_{PD}) \cos(\Theta_{PD}) \cos(\omega_{PD}) \sin(\Theta_{PD}) ]^T. \]

C. Signal Combining Scheme

LiFi uses intensity modulation (IM) at the transmitter and the direct detection (DD) at the receiver. Therefore, the transmit signals must be positive and real. According to direct current biased optical orthogonal frequency division multiplexing (DCO-OFDM) is used in this study. There are different signal combining schemes such as equal gain combining (EGC), select best combining (SBC) and maximum ratio combining (MRC). An important metric to evaluate the link quality and capacity is the SINR. According to [7], after signal combining, the SINR between user μ and the serving APa is given by:

\[ \gamma_{μ,a}(f) = \sum_{p=1}^{N_{PD}} \sum_{k} \frac{\tau_{k} \left| w_p H_{μ,a,p}(f) \right|^2}{\sum_{k} \left| w_p H_{μ,a,p}(f) \right|^2}, \]

where \tau is the optical to electrical conversion efficiency at the receivers; wp is the combining weight of PDp; \kappa is the ratio of DC optical power to the square root of electrical signal power, \kappa = 3 can guarantee only around 0.3% of the signals will be clipped so that the clipping noise can be neglected; N0 is the noise power spectral density in LiFi link, which is assumed to follow a Gaussian distribution; BL denotes the LiFi baseband modulation bandwidth; \tau, Hμ,a,f is the angle of incidence to the PDs can be written as \varphi = \arccos \left( nPD,d \right), where <,> is the inner product operator.
channel gain in the frequency domain between the PDP of user $\mu$ and the serving APs; $H_{a_p,\mu}(\Omega)$ is the channel gain in the frequency domain between the PDP of user $\mu$ and the interfering LiFi AP $ai$. In the EGC scheme, signals from all PDPs are combined with equal weights. Hence, $w_p=1$, for $p\in P$. The SBC scheme only selects the information from the PD with the highest received SINR instead of SNR in [7]. Thus, the selected PD is determined by

$$p_s = \arg \max_{p\in P} \left( \frac{\beta_p}{\tau_{\Phi_s}} \right)^2 N_0 B_L + \sum_{a_i \in A \setminus \{a_s\}} \left( H_{a_1,\mu,p}(0) \right)^2$$

and the weight of each PD is given by:

$$w_p(f) = \left( \frac{\beta_p}{\tau_{\Phi_s}} \right)^2 N_0 B_L + \sum_{a_i \in A \setminus \{a_p\}} \left( H_{a_1,\mu,p}(f) \right)^2$$

III. LOAD BALANCING

EGT Based APS Scheme An EGT based load balancing scheme is proposed for the APS and handover. The EGT based scheme is performed at the beginning of each state to determine the serving AP for each user. The evolutionary game for APS in each state can be formulated. Player Set(U): The users in the LiFi network are the players in the game and the set of players is denoted as $U=\{\mu | \mu \in [1,NUE]\}$. 2. Strategy Set(S$\mu$): In a LiFi network, the strategy set for each player is the set of LiFi APs. There fore, $S_\mu = \{a | a \in [1,Nl]\}$. 3. Population: In the proposed game, each player should be connected to a LiFi AP. The set of users served by the APs is $Ua$ and the population in this set is $Ma$. 4. Payoff function: The user QoS is considered as the pay off function as it represents the satisfaction level of each user regarding the AP selection. In general, the satisfaction level would increase along with the data rate. However, the user will be fully satisfied when the data rate increases to the required data rate $\lambda_\mu$ and the further increase of data rate will not bring any benefit regarding the QoS. Hence, the payoff function of the user $\mu$ served by the APs is given by:

$$\pi_{\mu,a} = \min \left\{ k_{\mu,a} \frac{\tau_{\mu,a}}{\lambda_\mu}, 1 \right\}$$

The APS strategy of each player in then-th iteration is based on the player’s payoff and the global average payoff in the last iteration, denoted as $\pi_\mu<\mu-1>,\pi_a$ and $\pi_\mu<\mu-1>$ respectively. The shift of strategy for each player occurs randomly and follows the principle that the player with a lower payoff would be more likely to change its strategy. This is termed as ‘mutation and selection mechanism’ in EGT [21]. Thus, in then-th iteration, the mutation probability for a strategy shift is denoted as:

$$p_{\mu}^t = \begin{cases} \frac{\pi_\mu<\mu-1>} {\pi_\mu<\mu-1>} & \pi_\mu<\mu-1> < \pi_\mu<\mu-1> \\ \frac{\pi_\mu<\mu-1>} {\pi_\mu<\mu-1>} & \pi_\mu<\mu-1> \geq \pi_\mu<\mu-1> \\ 0 & \pi_\mu<\mu-1> = \pi_\mu<\mu-1> \end{cases}$$

A. Convergence Analysis

In general, an evolutionary equilibrium (EE), referred to as the Nash Equilibrium [10], can be achieved when a convergence is reached. Definition 1: A strategy profile $E=\{a_\mu | \mu \in U\}$ is an EE of the proposed load balancing game if at the equilibrium $E$, no player can further increase their payoff by unilaterally changing its strategy, i.e.:

$$\pi_{\mu,a_\mu} \geq \pi_{\mu,a_\mu}, \quad a_\mu \neq \beta_\mu, \quad a_\mu, \beta_\mu \in S_\mu.$$
AP, passing through the overlapping region. It then moves from the LiFi AP to the Wi-Fi AP. This preliminary result shows that the time for horizontal handover is shorter than the time for vertical handover, as shown in Fig. 8. In both handover events, the users experience short service disruption, which, however, is not noticeable as the service is running in a buffered mode. In Fig. 9, the SNR is plotted when the user moves away from the center of the LiFi AP. The SNR is determined via system level simulations and measurements. The LiFi AP provides a high SNR around the cell center, which can be exploited to achieve very high data rates using adaptive modulation and coding techniques. It also shows the spatial confinement of the light signal, which can be harnessed to build ultra-dense wireless networks (within 1 m the SNR has dropped by 15 dB). In the next section, we provide results of a real-world LiFi network deployment in a school. D. Real-World Use Case: LiFi-Enabled Traffic Offloading in a Classroom In this section we present the results of a real-world use case where a LiFi network was deployed in a classroom in addition to a Wi-Fi network. The network topology consists of eight LiFi attocell APs, as shown in Fig. 10. The LiFi attocell APs exist with two additional Wi-Fi APs that serve seven class-rooms. The Wi-Fi APs are commercially available and based on the IEEE 802.11ac standard. Each Wi-Fi AP can support data rates between 300 and 867 Mbps, depending on the mode of operation and bandwidth.

IV. CONCLUSION

For a single PD receiver system and ADRs with EGC, the proposed scheme has the same performance as the SSS-based APS scheme. However, when the ADR with SBC and MRC are considered, the proposed scheme greatly outperforms the SSS-based APS. The performance gap will increase as the number of users and the required data rate increase. The MRC scheme using the proposed sub-optimum weights achieves similar performance to the MRC scheme using the optimum weights and outperforms all the other schemes.

V. REFERENCES


