Dynamic Load Balancing for Hybrid Li-Fi and RF Indoor Networks

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***Abstract*—In this paper, a dynamic load balancing problem for a mobile hybrid Li-Fi and mm wave RF network is studied. Even though Li-Fi networks can provide extremely high data throughputs, the spatial distribution of such high data rates may not be uniform. It has been shown that this spatial data rate fluctuations can be successfully reduced by a RF network augmented to the Li-Fi network. In this study, a dynamic load balancing algorithm is proposed to find the optimum access point (AP) assignment in order to satisfy certain average per user data rate constraints while achieving minimum outage performance. Furthermore, a data rate threshold is defined to identify whether users should be served by a Li-Fi AP or a RF AP. The simulation results show that this threshold has a significant effect on the outage performance of the hybrid network. The results further show that the optimum threshold which achieves the minimal outage probability is much lower than the per user data rate requirements.**

***Index Terms*—Li-Fi, RF, outage, dynamic load balancing, handover overhead**

I. Introduction

The radio frequency (RF) spectrum has become a very limited resource due to the increasing demand of wireless and mobile data. Light Fidelity (Li-Fi) technology, which uses 300 THz licence-free and unused optical spectrum for wireless communication is proposed as a potential solution [1]. In Li-Fi systems, a high data rate can be achieved by using intensity modulation and direct detection (IM/DD) with optical orthogonal frequency multiplexing (OFDM). Recently, transmission speeds of 3 Gbp/s by a single colour light emitting diode (LED) are reported [2].

In indoor environments, a Li-Fi cell covers only a few square meters due to the intrinsic properties of light. Generally, there can be many light sources in a room, and high spatial spectral efficiency can therefore be achieved by Li-Fi. However, in spite of the dense deployment of access points (APs), Li-Fi does not provide a uniform coverage because optical signals are susceptible to blockages. When the light beams are blocked, the supported data rate is reduced due to the low optical channel gain. It has been shown that even though Li-Fi networks can provide very high data rates, the outage rate performance in multiuser environment can still be significantly low [3]. It has been further shown in [3] that a properly designed hybrid Li-Fi and RF network (e.g. mm Wave RF) can successfully improve both the average and outage data rate performance. Since RF and Li-Fi rely on non-overlapping spectrum, hybrid networks could potentially combine the benefits of both Li-Fi and RF systems. On the one hand, this hybrid integration can provide a sum system throughput greater than that of Li-Fi or RF standalone networks without creating mutual interference. On the other hand, RF systems can achieve ubiquitous coverage which ensures moderate throughput at all locations. Accordingly, the combine effect of Li-Fi/RF hybrid network can significantly improve both system throughput and the user experience.

In this study, user data rate is considered as the quality of service (QoS), and an average throughput requirement of each user over the working period is taken into consideration. In practical systems, when user mobility is considered, users would experience many handovers when moving from one cell to another. During such handovers, the signalling information is exchanged between users and the central unit (CU). This process takes an average time ranging from around 30 ms to 3000 ms [4]–[6], depending on the algorithm used. In this study, a dynamic load balancing scheme which focuses on AP assignment for hybrid networks is proposed where the handover overhead is also considered. In the proposed scheme, users with high optical channel gains are preferentially allocated to Li-Fi APs. A data rate threshold is used to identify whether a particular user is served by a Li-Fi AP or a RF AP. The outage probability of the average throughput is analysed, and the relationship between the average throughput and the threshold is studied. In addition, given the outage constraints, the optimal threshold which achieves the maximal average throughput for each user is identified.

The rest of the paper is organised as follows. The mobile hybrid Li-Fi and RF system model is introduced in Section II. The handover overhead model and the dynamic load balancing scheme are given in Section III. The performance evaluation and discussion are given in Section IV, and the conclusion is followed in Section V.

II. System Model

A. System setup

An indoor Li-Fi/RF hybrid network for the downlink is considered, where several Li-Fi and RF APs are deployed. The number of Li-Fi and RF APs are denoted as N_v and N_r, respectively. Each Li-Fi AP consists of an LED lamp which is constructed from several LEDs. It is assumed that all of the photon detectors (PD) in the mobile are oriented perpendicular to the ground. This means the angle of irradiation is equal

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to that of incidence. The field of view (FoV) of the LEDs and PDs can be designed so that the transmission can be contained within a certain space. Also, walls of a room block light completely which means that co-channel interference (CCI) can be fully avoided between rooms. Thus, each Li-Fi AP in this model covers a confined cell, referred to as an optical attocell. Additionally, all of the Li-Fi APs reuse the same bandwidth, and users that reside in the overlapping area of Li-Fi attocells and are served by the Li-Fi APs would experience CCI. CCI is considered in this study, and is treated as additional noise.

In this network, users are randomly distributed in the coverage area. Due to the bandwidth resue of Li-Fi APs, the Li-Fi system can provide high spatial spectral efficiency to users [7]. However, the optical channel state information (CSI) of mobile users fluctuates over the coverage area, and the optical channel gain can be very low when the light beams are blocked. To improve the user data rate performance, the system is augmented by a RF network. The RF APs are assumed to cover the entire indoor scenario. To avoid CCI in the RF system, each RF AP is allocated a non-overlap spectrum for transmission. The total bandwidth and power consumption constraints for RF APs are denoted as B_R and P_R, respectively. The bandwidth and power can be dynamically allocated to each RF AP according to the data rate requirement of users.

In this model, to better utilise the high spatial spectrum efficiency of Li-Fi, users with high optical channel gains are allocated to Li-Fi APs. Users which have low optical CSI are served by RF APs. Due to the mobility of the receivers, the CSI of both Li-Fi and RF communication links changes so that the resource allocation should be done regularly within certain time intervals. In this study, it is assumed that the CSI of users changes slowly, which means the CSI remains stable during a short period. Accordingly, the working process of the system can be divided into different states within very short time intervals. In the model, a central unit (CU) is assumed to monitor the system continuously at an interval time T_p, and this is equivalent to the frame duration of the physical layer. Here, the period of time T_p is defined as a state where all of the users receive the allocation results from the CU and receive signals from APs with constant data rates. A natural number *n* is denoted as the sequence number of the state.

During the movement of users, a handover occurs when a user is served by two different APs in two neighbouring states, and the overhead is considered. In this study, a load balancing algorithm used in each state is proposed. The proposed algorithm contains AP assignment and transmission resource allocation. Specfically, a threshold of data rate is introduced, denoted as γ. Users with the data rate of Li-Fi greater than γ are allocated to Li-Fi APs, and others are allocated to RF APs.

Moreover, the hybrid system has an averaged data rate requirement for each user, denoted as Γ. During the working period, the achieved average data rate of each users should be higher than this requirement. The objective of this study is to find out how the threshold γ affects the outage of the average data rate requirement.

Here N_u is denoted as the number of the users; N_s is denoted as the number of the working states; $\mathcal{C}_{\mathcal{L}} = \{v|v \in [1, N_v], v \in \mathbb{Z}\}$ is denoted as the set of optical attocells; and $\mathcal{C}_{\mathcal{R}} = \{r|r \in [1, N_r], r \in \mathbb{Z}\}$ is denoted as the set of RF cells.

B. Li-Fi channel model

According to [8], the optical channel gain of a line of sight (LoS) channel is defined as:

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

where m is the Lambertian index which is a function of the half-intensity radiation angle $\theta_{1/2}$, expressed as $m = -1/\log_2(\cos(\theta_{1/2}))$; A_p is the physical area of the receiver photo-diode; z is the horizontal distance from a Li-Fi AP to the optical receiver; h is the height of the room; ϕ is the angle of irradiation and θ is the angle of incidence; Θ_F is the half angle of the receiver's FoV; $T_s(\theta)$ is the gain of the optical filter; and the concentrator gain $g(\theta)$ can be written as:

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

where χ is the refractive index.

In a Li-Fi system, the LED lamps work in the linear region where the output optical power is proportional to the input voltage. Also, intensity modulation and direct detection (IM/DD) is used so that only positive real-valued signals can be transmitted to receivers [9]. A DC bias voltage source x_{DC} is added to the modulated electric signals before Li-Fi transmission. The conversion between the average electric power of signals and the average optical power obeys the following relationship $\iota = P_{\text{opt}}/\sqrt{P_t}$ [10], where P_{opt} is the average transmitted optical power of Li-Fi AP which is proportional to x_{DC}; and P_t is the electric power of the signals. For a given user μ connected to a Li-Fi AP α, the signal-to-interference-plus-noise ratio (SINR) can be written as:

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

where κ is the optical to electric conversion efficiency at the receivers; N_0 [A^2/Hz] is the noise power spectral density; $H_{\mu,\alpha}$ is the channel gain between user μ and Li-Fi AP; and $H_{\mu,\text{else}}$ is the channel gain between user μ and the interfering Li-Fi APs, according to (1).

Moreover, direct current biased optical orthogonal frequency-division multiplexing (DCO-OFDM) is employed in order to ensure real-valued signals are transmitted to receivers [9]. Thus, at least half of the sub-carriers must be used to realise the Hermitian conjugate of the complex-valued symbol after modulation. Consequently, only half of the bandwidth can be exploited for signal transmission in state *n*. Shannon capacity is used for calculating the achievable data rate between user μ and Li-Fi AP α, which can be expressed as:

$$R_{\mu,\alpha}^{(n)} = \frac{B_L}{2} \log_2(1 + \mathrm{SINR}_{\mu,\alpha}^{(n)}), \tag{4}$$

where B_L is the bandwidth for optical signal transmission.

In this study, time division multi-access (TDMA) method is employed, and proportional fair schedulers are considered. According to [11], all of the users served by a Li-Fi AP share an equal time resource when proportional fairness is achieved.

C. RF channel model

In the RF cell, an omni-directional transmit antenna is used for each RF AP. The orthogonal frequency division multiplexing access (OFDMA) is employed in the RF system. It is assumed that the frequency response of the channel is flat due to negligible power from reflected paths so that all of the sub-carriers allocated to a specific user have the same CSI. The RF channel gain between users and RF APs is given by:

$$h = \sqrt{10^{\frac{-L(d)}{10}}} \left(\sqrt{\frac{K}{1+K}} h_d + \sqrt{\frac{1}{1+K}} h_s \right), \tag{5}$$

where $K = 10$ dB is the Rician factor for indoor 60GHz mm Wave links [12]; $h_d = \sqrt{1/2}(1+j)$ is the fading channel of the direct path; $h_s \sim \mathcal{CN}(0,1)$ is the fading channel of the scattered path; and $L(d)$ is the corresponding large-scale fading loss in decibels at the separation distance d, given by [13]:

$$L(d) = L(d_0) + 10\nu \log_{10}(d/d_0) + X, \tag{6}$$

where $L(d_0) = 68$ dB is the reference path loss at some reference distance $d_0 = 1\ m$; $\nu = 1.6$ is the path loss exponent; and X is the shadowing component which is assumed to be a zero mean Gaussian distributed random variable with a standard deviation of 1.8 dB. The shadowing effect induced by human bodies in the proximity of the mm Wave radio links is omitted [14].

It is assumed that each sub-carrier is allocated equal power, and each user can be dynamically allocated sub-carriers for transmission. According to [15], the data rate achieved by the RF link between user μ and RF AP α in state n can be expressed as:

$$\Upsilon_{\mu,\alpha}^{(n)} = B_\mu \log_2(1 + \frac{|h_{\mu,\alpha}^{(n)}|^2 P_R}{N_0 B_R}) \tag{7}$$

where B_μ is the bandwidth allocated to user μ in RF system; and $h_{\mu,\alpha}^{(n)}$ is the RF channel gain between user μ and AP α according to (5). Here, Λ_μ is defined as the proportion of the bandwidth that user μ obtains. Thus, B_μ can be expressed as:

$$B_\mu = \Lambda_\mu B_R. \tag{8}$$

To improve the data rate performance of each user, an adaptive RF bandwidth allocation is used. The details are given in Section III.

Algorithm 1 Dynamic algorithm executed by CU.

```
Initialisation: denote α'_μ as the AP allocated to user μ in
  state n − 1, n ← 1;
while n ≤ N_s do
    Obtain the Li-Fi and RF CSI between each μ and α.
    Calculate R^(n)_{μ,α} and Υ^(n)_{μ,α} according to the CSI.
    Calculate η^(n)_{α'_μ α} between each μ and α.
    Calculate the load balancing result by using R^(n)_{μ,α}, Υ^(n)_{μ,α}
      and η^(n)_{α'_μ α}, according to Algorithm 2.
    Restore the AP allocated to user μ in state n as α'_μ.
    n ← n + 1;
end while
```

III. Dynamic Load Balancing Scheme

A. Dynamic algorithm with handover

In a dynamic system, when two different APs serve a user in two neighbouring states, a handover occurs. During the handover, there is no effective data received by the users. This results in overhead and spectrum efficiency losses which are considered in this study. Specifically, handovers can be classified into four types: from RF AP to Li-Fi AP; from Li-Fi AP to RF AP; from Li-Fi AP to a different Li-Fi AP; and from RF AP to a different RF AP.

The overhead of different type of handovers in an indoor network is in the order of milli-second (ms) [4]. This overhead is assumed to be much lower than the interval time T_p between two states. In a practical system, the overhead cannot be a fixed value due to the delay of signalling interaction. Poisson distribution is considered an appropriate model to describe it [16]. Hence in this study, the overhead of different types of handovers is modelled as a random variable with independent identical Poisson distribution. The probability mass function is given by:

$$\Pr(t_{ij} = x) = \frac{\zeta_{ij}^x e^{-\zeta_{ij}}}{x!}, \quad x = 0, 1, 2... \tag{9}$$

where t_{ij} is the overhead of the AP switch from AP i to AP j; and $\zeta_{ij} = \mathbb{E}[t_{ij}]$ is the mean of the overhead.

Since a handover results in a loss of throughput between the AP and the user, the transmission efficiency between two neighbouring states can be written as:

$$\eta_{ij} = \begin{cases} \left[1 - \dfrac{t_{ij}}{T_p}\right]^+, & i \neq j \\ 1, & i = j \end{cases}, \quad i, j \in \mathcal{C_L} \cup \mathcal{C_R}. \tag{10}$$

where the operation $[.]^+$ represents $\max(\ .\ , 0)$. The effective data rate with handover between each AP and user can be expressed as the product of efficiency in (10) and the communication link data rate.

In this system, each user is allocated to a Li-Fi or RF AP in each state. During the working period, users move randomly in the indoor senairo, and the APs allocated to users would be changed according to the user location. The CU calculates the allocation result in each state with handover considered. The dynamic algorithm executed by the CU in N_s working states is shown in Algorithm 1. The specific load balancing algorithm is given in subsection III-B.

B. Load balancing algorithm in each state

In this subsection, a load balancing algorithm with AP assignment and transmission resource allocation is proposed. For simplicity, the superscript of (n) is omitted in this part. For user μ, the serving AP in state $n-1$ is denoted as α'_μ. In each state, to fully utilise the high spatial spectral efficiency of Li-Fi, users would be firstly allocated to Li-Fi APs. By using the data rate threshold γ, users that achieve lower data rates than this threshold are re-allocated to RF APs.

In the first allocation part, a criterion of maximal effective throughput is applied. For user μ, the Li-Fi AP achieving the highest communication link data rate with handover can be expressed as:

$$\beta_{1,\mu} = \arg\max_{j\in\mathcal{C_L}} \ \eta_{\alpha'_\mu j} R_{\mu,j}. \tag{11}$$

Due to the equal time resource shared by the users when allocated to a Li-Fi AP, the optical data rate for each user can be written as:

$$\Omega_\mu = \eta_{\alpha'_\mu \beta_{1,\mu}} \frac{R_{\mu,\beta_{1,\mu}}}{M_{\beta_{1,\mu}}}, \tag{12}$$

where $M_{\beta_{1,\mu}}$ is the number of users served by Li-Fi AP $\beta_{1,\mu}$.

In the re-allocation part, users satisfying the condition $\Omega_\mu < \gamma$ are re-allocated to RF APs. In the RF system, the data rates of users also need to be improved to satisfy the average data rate requirement. Initially, an optimal RF AP is allocated to the users according the CSI in the current state. Similar to the Li-Fi system, the criterion of maximal effective throughput is employed for AP allocation in the RF system. The optimal RF AP for user μ can be expressed as:

$$\beta_{2,\mu} = \arg\max_{j\in\mathcal{C_R}} \ \eta_{\alpha'_\mu j} \Upsilon_{\mu,j}, \quad \Omega_\mu < \gamma. \tag{13}$$

In addition, an adaptive bandwidth allocation is used, which considers the average data rate achieved in the previous states. To improve the data rate of users with a previous low average data rate, the proportion of bandwidth Λ_μ can be designed as:

$$\Lambda_\mu = \frac{1/\lambda_\mu}{\sum_{x\in U_R} 1/\lambda_x} \tag{14}$$

where λ_μ is the average data rate in the previous states for user μ; and $\mathcal{U_R}$ is set of the users served by RF APs in the current state. By using this bandwidth allocation method, the data rate performance of some users can be enhanced. The proposed load balancing algorithm is summarised in Algorithm 2.

According to (11) and (13), the AP allocated to user μ in state n can be expressed as:

$$\alpha_\mu = \begin{cases} \beta_{1,\mu}, & \Omega_\mu \geq \gamma \\ \beta_{2,\mu}, & \Omega_\mu < \gamma \end{cases}. \tag{15}$$

Algorithm 2 Load balancing algorithm in state n

```
Initialisation: R^(n)_{μ,α}, Υ^(n)_{μ,α} and η^(n)_{α'_μ α}
for all user μ do
    Calculate β_{1,μ} according to (11).
    Calculate the potential Li-Fi data rate Ω_μ according to (12);
    if Ω_μ ≥ γ then
        User μ is allocated to Li-Fi AP β_{1,μ}.
    else
        User μ is allocated to RF AP β_{2,μ}, according to (13).
        Calculate the allocated RF bandwidth Λ_μ, according to (14).
    end if
    Calculate the achievable data rate according to (16).
    Calculate the average data rate over all of the states, denoted as λ_μ.
end for
```

C. Outage probability of the average data rate requirement

According to Algorithm 2, the allocated AP α_μ can be determined in each state. Thus, the achievable data rate of user μ can be expressed as:

$$r_\mu^{(n)} = \begin{cases} \eta_{\alpha'_\mu \alpha_\mu} \dfrac{R_{\mu,\alpha_\mu}}{M_{\alpha_\mu}}, & \alpha \in \mathcal{C_L} \\ \eta_{\alpha'_\mu \alpha_\mu} \Lambda_\mu \Upsilon_{\mu,\alpha_\mu}, & \alpha \in \mathcal{C_R} \end{cases}, \tag{16}$$

where M_{α_μ} is the number of users served by Li-Fi AP α_μ. With the average data rate requirement Γ in the hybrid system, the outage probability of the QoS requirement can be expressed as:

$$\Delta = \Pr\Big(\frac{1}{N_s} \sum_{n=1}^{N_s} r_\mu^{(n)} < \Gamma \Big). \tag{17}$$

Based on the proposed dynamic load balancing algorithm, the threshold γ can significantly affect the outage probability. In Section IV, the simulation results of the effects of this parameter are presented.

IV. Numerical Results and Discussion

In this section, the outage probability of the QoS requirement is evaluated by Monte Carlo simulation. Firstly, the system setup is introduced, then the simulated results of outage are discussed.

A. System setup

In the simulation, a 40 × 40 metres open office space is considered. This indoor scenario is covered by 16 Li-Fi APs and 4 RF APs is considered, shown in Fig. 1. All of the Li-Fi APs reuse the same bandwidth and the CCI between adjacent Li-Fi attocells is treated as noise. All of the users are uniformly distributed and move with random speeds that are uniformly distributed between 0 and 2 metres per second.

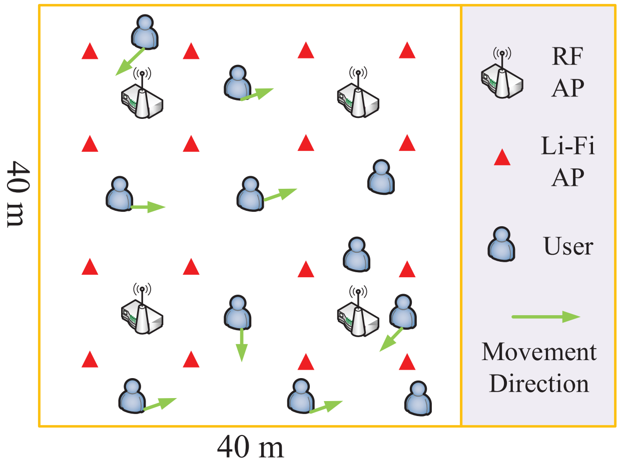

Fig. 1. Simulation Scenario

TABLE I
SIMULATION PARAMETERS

Name of Parameters	Value
Height of the room, h_r	3.5 m
Transmitted optical power per Li-Fi AP, P_t	9 W
Modulation bandwidth for LED lamp, B	40 MHz
The physical area of a PD, A_p	1 cm^2
Half-intensity radiation angle, $\theta_{1/2}$	60 deg.
Gain of optical filter, $T_s(\theta)$	1.0
Receiver FoV semi-angle, Θ_F	90 deg.
Refractive index, χ	1.5
Optical to electric conversion efficiency, γ	0.53 A/W
Total transmitted power for each RF AP, P_R	1 W
Total transmitted bandwidth for each RF AP, B_R	20 MHz
Noise power spectral density, N_0	10^{-21} A^2/Hz
Resource allocation interval of central unit, T_p	500 ms
The working time of the dynamic system, T	2 min

The direction of the movement of each user changes randomly every five states, which is uniformly distributed between 0 and 2π. When users come to the boundary of the room, they would change the direction towards the centre in the current state. A handover occurs when two APs are allocated to a user in the neighbouring states. The handover overhead is independently identically Poisson distributed. There is an average data rate requirment for the users in the hybrid network, denoted as Γ. The number of users in the simulation is 60. The other parameters are given in Table I. In the simulation, the outage probability is calculated according to (17) by assuming 5000 realisations of the dynamic system.

B. Outage Performance Evaluation

In Fig. 2, the outage probability is presented, where the mean of the handover overhead is 25 ms. As shown, the outage probability is a convex function corresponding to the threshold γ. The lowest outage probability with 30 Mb/s data rate requirement is achieved when the threshold is set at approximately 9 Mb/s. When a threshold $\gamma < 9$ Mb/s is used, the Li-Fi system is overloaded so that the outage probability increases. On the other hand, the outage performance can be affected by the overload of RF system by using a threshold

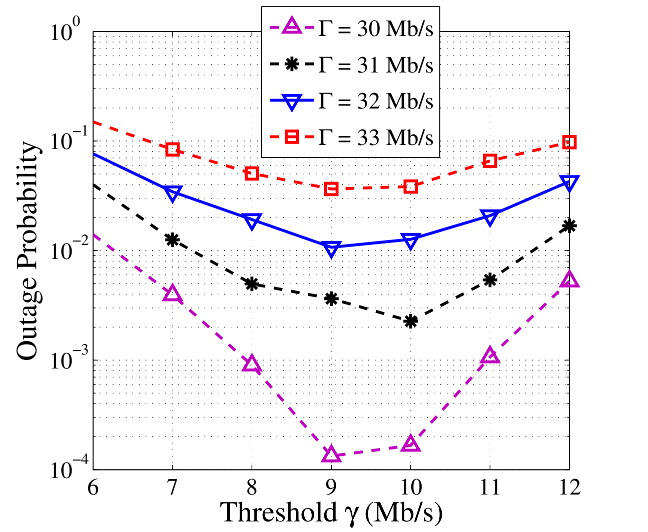

Fig. 2. Outage Probability (The expectation of the handover overhead is 25 ms)

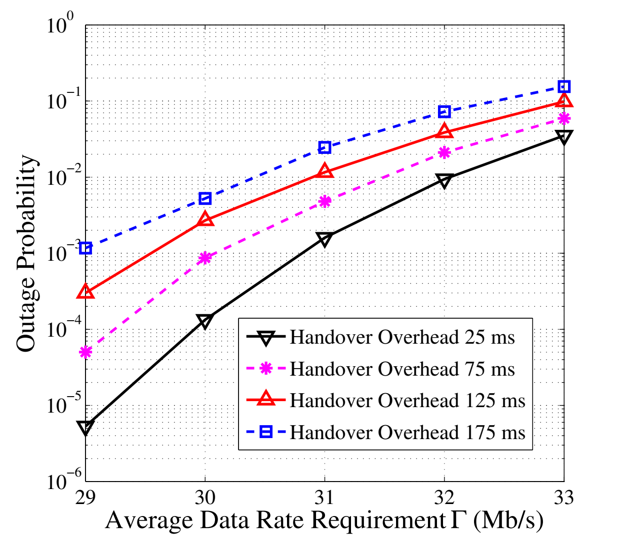

Fig. 3. Outage probability with optimal threshold obtained from the simulation result

$\gamma > 9$ Mb/s. Also, it can be seen that an optimal threshold employed in the Algorithm 2 is much lower than Γ. This is because that after users with low data rates of Li-Fi are re-allocated to RF APs, the time resource shared by each user allocated to Li-Fi APs increases. Thus the achievable data rate in Li-Fi system becomes much higher than the threshold.

The outage probabilities achieved by the optimal threshold with different handover overhead are given in Fig. 3. It shows that the outage probability increases with respect to the required average data rate and the handover overhead. In this simulation, a 50 ms delay of the handover overhead leads to an approximately 5 dB increase of the outage probability when Γ is close to 30 Mb/s. It can be seen that the outage probability decreases with a reduction of QoS requirement.

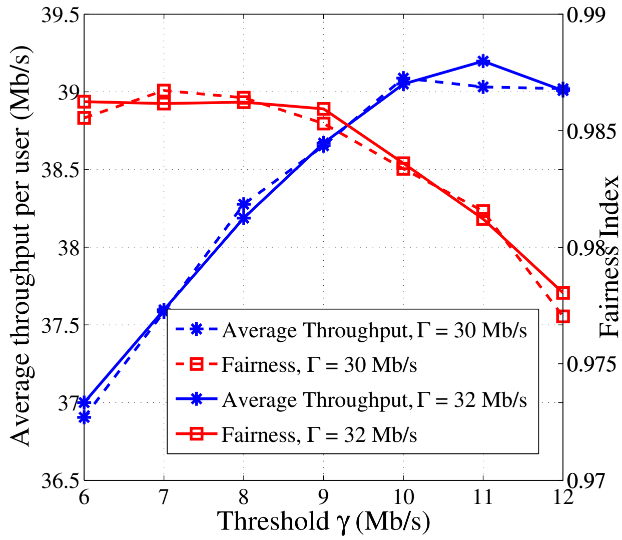

Fig. 4. Average data rate and fairness index (handover overhead 25 ms)

When $\Gamma = 29$ Mb/s, the outage probability is less than 10^{-3}, according to Fig. 3. In this case, the outage performance is high enough so that the lowering Γ further would not gain additional insights.

In Fig. 4, the average user throughput and user fairness are considered. Here, a fairness index is applied to evaluate user fairness [11], which can be expressed as:

$$I = \frac{(\sum_{i=1}^{i=N} x_i)^2}{N \sum_{i=1}^{i=N} x_i^2} \tag{18}$$

where I is the fairness index; x_i is the achievable data rate of each user; and N is number of the users. The fairness index is a fractional value between 0 and 1, where 1 represents perfect user fairness. As shown in Fig. 4, the threshold also has an effect on the average data rate and the fairness index. An optimal fairness index is achieved when the threshold is set to be 7 Mb/s appropriately. The value of the fairness index decreases monotonically When $\gamma > 7$ Mb/s. On the other hand, the value of average data rate reaches an optimum with a threshold of 11 Mb/s. According to Fig. 2, the threshold to achieve the best outage probability is around 9 Mb/s. This indicates that there is a trade-off among the performance of data rate, fairness and outage. Since the optimal values of γ for the three objectives are very close, a compromise can easily be made. Intuitively, $\gamma = 9$ Mb/s can achieve a good performance of the three objectives in this simulation. In this case, the outage probability is optimised, and the average data rate and the fairness index are both close to the their optima.

V. Conclusion

In this study, a dynamic load balancing scheme for a Li-Fi/RF network with handover and user QoS considered is proposed. This scheme contains AP assignment and transmission resource allocation for users. The aim is to improve the performance of user data rates and outage of the required average throughput. Due to the high spatial spectral efficiency of Li-Fi, users that can achieve data rates greater than the threshold are allocated to Li-Fi APs so that the optical channel gains can be fully exploited. In addition, an adaptive bandwidth allocation is employed in the RF system to improve the performance of user data rates. The simulation results indicate that a low outage probability can be achieved by using an appropriate threshold. The value of the optimal threshold is always much lower than the average data rate requirement because the load of both Li-Fi and Wi-Fi systems are well balanced. Moreover, the threshold to achieve the optimum average data rate, fairness index and outage probability are very close. This means it is possible to find a good compromise of the trade-off among throughput, fairness and outage without heavily sacrificing any of these metrics.

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