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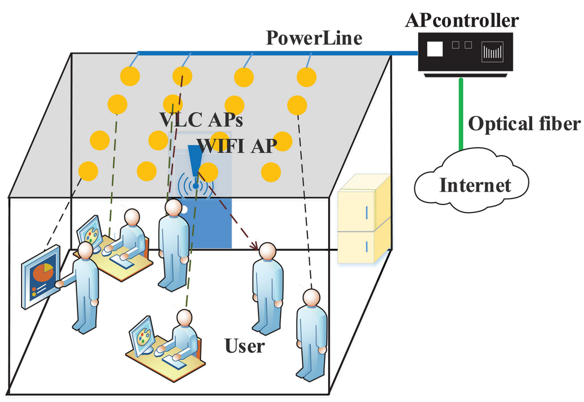

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User-Centric Access Scheme Based on Interference Management for Indoor VLC-WIFI Heterogeneous Networks

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Abstract: VLC-WIFI heterogeneous networks have become a promising solution, where VLC and WIFI are collaborating on providing services for indoor users. The dense deployment of visible light communication multiple access points (APs) can expand the system capacity, but it leads to complicated inter-cell interference (ICI). In order to arrange users to access the appropriate AP and implement interference management, a novel scheme called user-centric access based on regular spectrum allocation (UCARSA) is proposed in the paper. In UCARSA, the sliced visible spectrum is assigned to VLC APs regularly, so that the user associated with more than one AP is impacted less by ICI. Furthermore, the virtual community is constructed for each user to balance the user rate and improve the average spectral efficiency. The above performance improvement can be proved by simulation results in this paper, and it shows that the performance of UCARSA is better than two kinds of comparison algorithms.

Index Terms: Visible light communication, heterogeneous networks, user-centric access, interference management, system throughput.

1. Introduction

With the development of the Internet of Things (IOT), the increasing number of mobile equipment has led to a rapid rise in mobile data traffic [1], [2]. Therefore, the limited radio spectrum has become an extremely scarce resource. Visible light communication (VLC) based on light emitting diode (LED) has become a broader unlicensed spectrum resources [3]–[5]. However, VLC uplink implementation is difficult and downlink line-of-sight (LOS) is easy to be blocked. Consequently, Wireless fidelity (WIFI) network and VLC network merges into the indoor VLC-WIFI heterogeneous networks owning the high transmission speed and large communication coverage area [6].

In indoor VLC-WIFI heterogeneous networks, for improving data rate, the user prefers to access the most suitable AP type. In [7], Liu *et al.* proposed a user access scheme based on the quality of service (QoS) decision to meet the needs of transmitter and receiver. Through evaluating the user

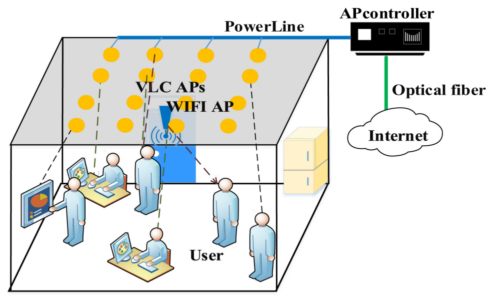

Fig. 1. VLC-WIFI heterogeneous networks model.

experience, a scheme based on the Markov model was proposed for AP decision in [8]. A joint load balancing and user access scheme, which mitigated the adverse effects caused by the user mobility and light path interruption, was proposed in [9]. For further increasing the user rate, P. Kuo *et al.* proposed the user-centric access (UCA) policy in [10], which allowed the user to access a virtual community (VC) composed of different types of APs. In [11], Feng *et al.* proposed a scheme in which multiple users access multiple APs at the same time. The AP served the user according to a distance threshold and the user accessed into a group of APs according to a signal strength threshold. In [12], Chen *et al.* grouped APs based on interference graph in a cell-free VLC network and the user only access APs scheduled in a cycle.

Although the grouping scheme can greatly increase the user rate, it produces the inter-cell interference (ICI) because of sharing resource. Power control, schedule and frequency reuse are main methods to achieve interference management (IM) in wireless communications. In [13], the ICI was reduced by power control, but the reduction of transmit power resulted in the less user rate simultaneously. In [14], the ICI problem was transformed into a graph theory model and interference was avoided by scheduling user group. However, the irrational priority setting easily lead to poor user fairness. In [15], a dynamic frequency reuse method was proposed to avoid ICI and improve throughput, but the complexity of searching the result of frequency reuse is high. In [16], a multi-level soft frequency reuse scheme was proposed for heterogeneous networks, which can avoid ICI by allocating mutually exclusive spectrum to the user in macro cell and the edge user in micro cells.

In this paper, the UCA scheme based on IM for indoor VLC-WIFI heterogeneous networks is proposed. In section 1, some user access schemes and IM methods are outlined. The VLC-WIFI heterogeneous networks model is introduced in section 2. The user-centric access based on regular spectrum allocation (UCARSA) algorithm is proposed in section 3. Simulation results and the conclusion are narrated in section 4 and section 5, respectively.

2. VLC-WIFI Heterogeneous Networks

Fig. 1 shows the VLC-WIFI heterogeneous networks model and the size of model is 10 m $\times$ 10 m $\times$ 3 m. 16 VLC APs arranged on the ceiling are responsible for the downlink transmission. A WIFI AP set at the center of the ceiling is responsible for the uplink and downlink transmission. The AP controller demodulates the information transmitted through the optical fiber. In addition, the controller records the identity document (ID) of the AP and user, the load of the AP, and the interference strength of the user. Besides, the process of user association and resource allocation is performed in the controller.

2.1 VLC Channel Model

In Fig. 2, LED is the point light source with a Lambertian radiation pattern. Information is transmitted through LOS downlink and finally received by the photoelectric detector (PD) configured on the

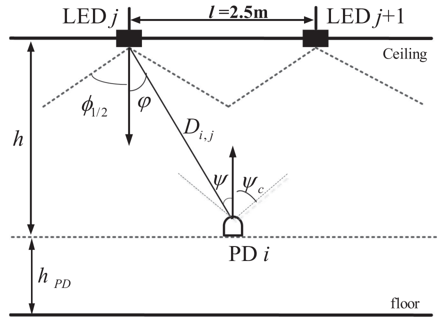

Fig. 2. Downlink transmission of VLC network.

mobile terminal. The VLC channel gain between PD i and LED j can be expressed as follows [17]:

$$H_{i,j}^V = \begin{cases} \frac{(m+1)A_{PD}}{2\pi D_{i,j}^2}\cos^m(\varphi)\cos(\psi)g(\psi)T(\psi), & 0 \le \psi \le \psi_c \\ 0, & \psi > \psi_c \end{cases} \tag{1}$$

where A_{PD} represents the receiving area of PD. m denotes the Lambertian radiation coefficient, $m = -\ln 2/\ln[\cos(\phi_{1/2})]$. $\phi_{1/2}$ is half power angle of the transmitter. $D_{i,j}^2$ is the distance between the PD i and the LED j. φ is launch angle of the LED j. ψ is the incidence angle of PD i. ψ_c is field of view (FOV) angle of PD. $T(\psi)$ is the gain of the optical concentrator, and the gain of the optical filter can be expressed as $g(\psi) = n^2/\sin^2(\psi_c)$.

The interference suppression is studied in this paper, thus calculating the interference power accurately is very important to measure the effectiveness of IM method. The received signal to interference plus noise ratio (SINR) from VLC AP j to user i is expressed as follows:

$$\xi_{i,j}^V = \frac{\left(\gamma P_i^V H_{i,j}^V\right)^2}{N^V B_{i,j}^V + \sum_{k\in\mathbf{A},k\neq j}\left(\gamma P_i^V H_{i,k}^V\right)^2}, \qquad j \in \{1, 2, \ldots, 16\} \tag{2}$$

Where γ is the optical-to-electric conversion coefficient, and P_t^V denotes the transmit power of VLC AP. N^V denotes the power spectral density of additive white Gaussian noise (AWGN), which is 1×10^{-21} A^2/Hz. $B_{i,j}^V$ denotes the bandwidth allocated by VLC AP j to user i. $\mathbf{A}$ is the VLC AP set. The maximum data rate $R_{i,j}^V$ of user i served by VLC AP j can be replaced by Shannon's capacity [18].

2.2 WIFI Channel Model

In the indoor WIFI network, channel model is set up by the IEEE 802.11, and the working frequency of WIFI is 2.4 GHz. The WIFI channel gain between WIFI AP and user i can be expressed as follows [19]:

$$H_i^W = |H_0|^2 \times 10^{\frac{-L(d_i)+X_\sigma}{10}} \tag{3}$$

Where $L(d_i)$ represents the path loss of WIFI in free space. H_0 denotes the channel transfer function, which obeys standard Rayleigh distribution. X_σ is a Gaussian random variable distributed with zero mean and a variance of 10dB.

The WIFI network utilizes orthogonal frequency division multiple access (OFDMA). The SINR from WIFI AP to user i is expressed as follows:

$$\xi_i^W = \frac{P_t^W H_i^W}{N^W B^W} \tag{4}$$

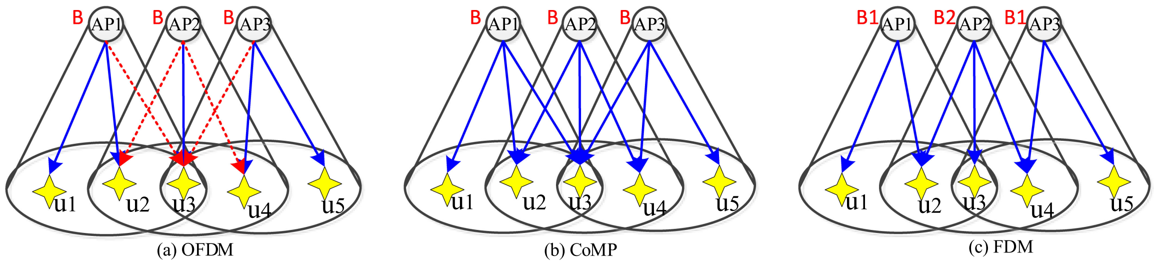

Fig. 3. Inter-cell interference management.

where P_t^W represents the transmit power of WIFI AP. N^W denotes the background noise power, which is -86 dBm. B^W represents the bandwidth of WIFI network. The maximum rate R_i^W of user i served by WIFI AP also can be replaced by Shannon's capacity.

2.3 Equivalent SINR Conversion and Threshold Setting

In this paper, the controller needs to assess the received SINR during user access. However, VLC and WIFI are not comparable in terms of SINR. An equivalent conversion method of SINR values is used in heterogeneous networks to convert $\xi_{i,j}^V$ to $\xi_{i,j}^T$, which can be compared with $\xi_{i,j}^W$, and the conversion equation can be found in [20].

If the FOV angle of the receiving device is large, the user covered by more than one AP will receive interference signal power. Therefore, the user overlapped is affected by ICI seriously and interference suppression needs to be performed in the VLC network. Furthermore, when the user receives a signal with a small FOV angle, it is obvious that the user is located in the central area of AP and the interference suppression is not necessary. Hence, a suitable threshold of the FOV angle, which is denoted as ψ_{th}, needs to be calculated. In addition, the threshold of the distance between the central user and the nearest AP is denoted as D_{th}.

3. User-Centric Access Scheme Based on Interference Management

In this section, the method of spectrum allocation at transmitter is designed firstly to eliminate ICI. Then, the process of virtual community construction is described in detail. By serving user with multiple APs, the user rate is generally improved. The user-centric access based on regular spectrum allocation (UCARSA) described in Algorithm 1, which includes the process of spectrum allocation at transmitter and virtual community construction. In addition, the implementation of UCARSA in indoor VLC-WIFI heterogeneous networks is designed, which can be described in Algorithm 2.

3.1 Spectrum Allocation at Transmitter

The schematic diagram of inter-cell interference management is shown in Fig. 3. The OFDMA technology is widely applied in LTE systems where the overlapped user may be subject to ICI, which can be expressed as the red dotted line with arrow in Fig. 3(a). An effective solution to avoid ICI is a technology called the coordinated multiple points (CoMP). Multiple APs serve overlapped users collaboratively, thus the interference power is converted into the useful signal power, as shown in Fig. 3(b). Inspired by the abovementioned method for interference suppression, a spectrum allocation method based on frequency division multiplexing at the transmitter is used, as shown in Fig. 3(c). Specifically, the system bandwidth B are divided into B1 and B2 respectively, and they are distributed to neighboring APs.

16 VLC APs are evenly deployed on the ceiling of room and the radiation angle of VLC AP is 60°. The projection of the VLC AP on the horizontal plane where the user receiving devices locate

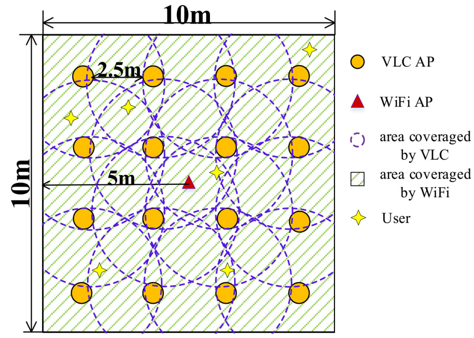

Fig. 4. VLC cell coverage area.

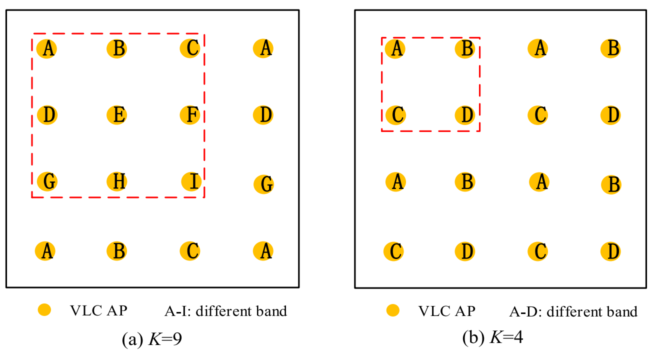

Fig. 5. Spectrum allocation method. (a) $K = 9$. (b) $K = 4$.

is shown in Fig. 4. The dense AP deployment results in a large overlapped area. When VLC APs transmit signals in the same frequency range, users in the overlapped area are affected by ICI severely. So, two kinds of spectrum allocation method based on frequency division multiplexing at the transmitter is designed. As shown in Fig. 5, the VLC spectrum is divided into K frequency bands and neighboring APs transmit signals in different frequency bands to avoid ICI. Even if a user located in the overlapped coverage area, different user information can be distinguished by frequency. K is set as 9 in Fig. 5 (a), and K is 4 in Fig. 5 (b).

3.2 Virtual Community Construction

The controller periodically tracks the location of all users and reconfigure the composition of VC. The controller customizes the exclusive VC for each user to make them located in the center of logical radio coverage, and the communication will no longer be interrupted by user mobility and link blocked [10]. The scheme based on VC construction has changed from the traditional "network control user" to "network service user", which greatly improves the experience of user and the quality of network. The UCARSA is designed as shown in Algorithm 1, which allocates frequency bands to VLC APs regularly and then reconstructs the VC for each user based on their channel gain.

In Algorithm 1, N_u is the number of users in the heterogeneous networks. M_a is the number of APs. When $H_{i,j} \neq 0$, user i is covered by AP j, and AP j is included in the candidate AP set of user i. $D_{th} = \sqrt{h^2 + (h \tan \psi_{th})^2}$, $\psi_{th} = \arctan(l/2h)$. Simultaneously, the label of the candidate AP is entered in the candidate matrix $\mathbf{C}_{N_u \times M_a}$, $c_{i,j} \in \{1, 2, \ldots, 17\}$. The association matrix $\mathbf{M}_{N_u \times M_a}$ is obtained at last, in which the association between APs and users are recorded in the form of Boolean variable. $\mathbf{G}$ is the set of users accessing the VLC network.

Algorithm 1: The User-Centric Access Based on Regular Spectrum Allocation.

1 **Input:** N_u, M_a, ψ_c and other necessary parameters,

2 Calculate $\mathbf{H}_{N_u \times M_a}$ according to (1) and (3), calculate $\xi_{N_u \times M_a}$ according to (2) and (4), calculate $\xi'_{N_u \times M_a}$, initialize $\mathbf{C}_{N_u \times M_a} = \{0\}$, $\mathbf{M}_{N_u \times M_a} = \{0\}$, $\mathbf{G} = \varnothing$.

3 *Step1:* the user selects the network.

4 For $i = 1$: N_u do

5 If $\xi_{i,17} > \xi'_{i,j},\ j \in \{1, 2, \ldots, 16\}$ then $m_{i,17} = 1$

6 Else $i \cup \boldsymbol{G}$

7 *Step2:* the strength of ICI is judged in the heterogeneous networks.

8 If $\psi_c < \psi_{th}$ then go to row **10**

9 Else go to row **12**

10 *Step3:* the spectrum allocation at transmitter is complied.

11 The spectrum is allocated to VLC APs as shown in Fig. 5(a) or Fig. 5(b), the label of frequency bands are recorded to $\mathbf{B}_{M-1}$.

12 *Step4:* the virtual community for each user is constructed.

13 For $i = 1$: $|\ \mathbf{G}\ |$ do

14 If $b_{c_{i,j}} = b_{c_{i,k}}, \quad \forall j, \forall k,\ j \neq k$ then

15 $a = max\{\xi_{i,1}, \ldots, \xi_{i,16}\},\ m_{i,a} = 1,\ m_{i,17} = 1$, back to row **13**

16 Else

17 For $j = 1$: M_a

18 If $\xi_{i,j} > 0$ then $m_{i,j} = 1$, back to row **17**

19 Else back to row **17**

20 Back to row **13**

21 For $i = 1$: N_u do

22 If $D_{i,j} \leq D_{th}$ then $m_{i,j} = 1$, back to row **21**

23 Else $m_{i,17} = 1$, back to row **21**

24 For $i = 1$: N_u, $i \notin$ **G** do

25 For $j = 1$: M_a

26 If AP j service less than two user then $m_{i,j} = 1$, back to row **25**

27 Back to row **24**

28 **Output:** $\mathbf{M}_{N_u \times M_a}$

Algorithm 2: The Implementation of UCARSA in Indoor VLC-WIFI Heterogeneous Networks.

1 The user requests permission to access the network through the uplink of WIFI.

2 WIFI AP receives the accessing request and then rely it to the central controller.

3 A new resource scheduling cycle begins.

4 **Algorithm 1** is applied in the central controller and the updated matrix $\mathbf{M}_{N_u \times M_a}$ can be obtained.

5 Every AP acquires some IDs of the user who needs to access the network.

6 AP evenly allocates the bandwidth owned by itself to each user associated with it.

7 Information of each user is sent to the corresponding receiver through the subchannel allocated by AP.

8 The central controller waits the end of the resource scheduling cycle or waits to be weak up by a new accessing request coming from WIFI AP.

9 If the accumulative number of times performing **Algorithm 1** is smaller than T then

10 Back to row **3**.

11 Else

12 The central controller statistics the user rate and evaluates the system performance.

13 End if

TABLE 1
Simulation Parameter

Symbol	Parameter	Value
$L \times W \times H$	room size	$(10\times10\times3)$ m^3
h_{PD}	the height of receiving device	1.2 m
P_t^V	the transmit power of LED	10 W
B^V	the bandwidth of VLC	40 MHz
$\phi_{1/2}$	half power angle of the transmitter	60°
$T(\psi)$	the optical convergence gain	1
n	reflectivity of walls	1.5
A_{PD}	the receiving area of PD	1 cm^2
γ	the photoelectric conversion coefficient	0.53 A/W
P_t^W	the transmit power of WIFI	20 dBm
B^W	the bandwidth of WIFI	22 MHz
T	the biggest accumulative number of times performing Algorithm 1	256

3.3 The User-Centric Access Scheme Based on Interference Management

The UCARSA is implemented in the controller and the process of implementing UCARSA is described in Algorithm 2. The number of T representing the biggest accumulative scheduling period of the UCARSA is chosen to statistical the average performance of the system.

4. Simulation Results

In this section, the UCARSA is simulated and some necessary parameters are shown in TABLE 1. A user-centric access strategy was adopted in [11], in which a fixed signal strength threshold and a distance threshold were utilized to make the association decision. A user association algorithm based on QoS was adopted in [7], in which the requirement of AP and user were considered in a balanced manner. The algorithm in [11] and [7] are compared with UCARSA here, named Basic-UCA and Based-QoS respectively. Furthermore, two kinds of spectrum allocation method of UCARSA are simulated, named UCARSA $K = 4$, UCARSA $K = 9$.

4.1 Performance Measurement

To measure the performance of networks, the system throughput (STP), average spectral efficiency (ASE) and service fairness index (SFI) are regarded as the performance indicator separately. To measure the experience of the user, the average user satisfaction index (ASI) is also regarded as the performance indicator.

In [12], the calculation of the spectral efficiency of the user was given to measure the average spectral efficiency, which is expressed as follows:

$$R_i = \sum_{j=1}^{J} \alpha_{i,j} \log\left(1 + \zeta_{i,j}\right) \tag{5}$$

where J denotes the number of APs included in the VC of user i. If the spectrum allocation at the transmitter is performed, $\alpha_{i,j} = 1/K$. Otherwise, $\alpha_{i,j} = 1$.

The Jain's index mentioned in [21] is referenced to quantify the service fairness and the higher value of it represents the better service fairness of the heterogeneous networks.

The user sends the minimum SNR requirement to the controller. If the achievable rate of the user is higher than the requirement rate, the user is satisfied with the service of the VLC-WIFI heterogeneous networks. Otherwise, the user is not satisfied with the service of networks. In [22],

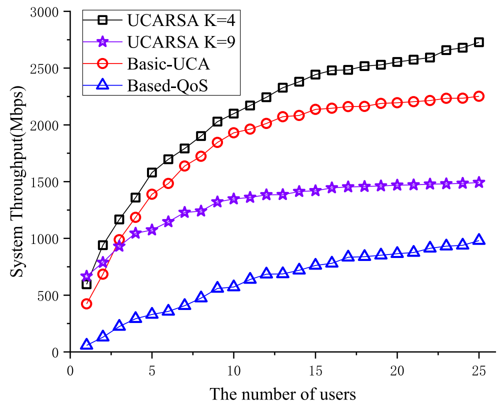

Fig. 6. System throughput performance. FOV = 60°.

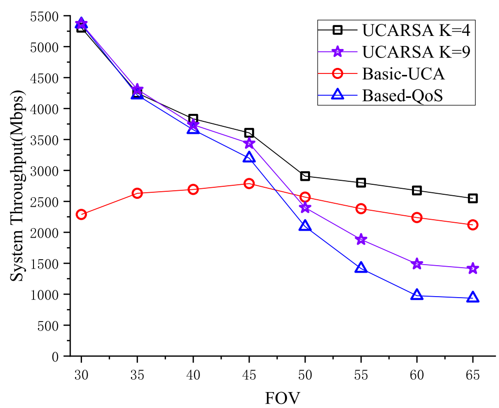

Fig. 7. System throughput performance. $N_u = 25$.

the user satisfaction index (USI) of user i is defined as follows:

$$U_i = \begin{cases} R_i/R_{re}, & R_i < R_{re} \\ 1, & R_i \geq R_{re} \end{cases} \tag{6}$$

where the user rate requirement $R_{re} = B_i \log(1 + \zeta_{re})$. B_i is the bandwidth allocated to user i. ζ_{re} is the minimum value of SNR, which represents the quality of experience of each user. The ASI is regarded as a performance indicator to measure the overall satisfaction index.

4.2 Performance Analysis of UCARSA

Fig. 6 shows that the STP of different algorithms are increasing with the increasing number of users. Both Basic-UCA and UCARSA are based on UCA method, thus the higher STP of them can be obtained. UCARSA $K = 4$ limits the size of VC, so that the restricted bandwidth of AP is distributed into the user with high channel quality, which improves the overall user rate. UCARSA $K = 9$ allocate less bandwidth to each AP, which limits the number of users accessing into AP. Therefore, the size of VC in UCARSA $K = 9$ is smaller than UCARSA $K = 4$, which results that the STP performance of UCARSA $K = 9$ is only higher than Based-QoS.

Fig. 7 shows the STP as a function of FOV. Since the VC of Basic-UCA was constructed with a fixed threshold, the change of FOV could not affect the STP seriously. The user of Based-QoS associated with an optimal AP, so the STP is close to UCARSA when FOV is small. When FOV gradually increases, the STP of Base-QoS decreases rapidly because of its failure in IM. During implementing UCARSA, the central user prefers to access VLC AP with the higher gain when FOV

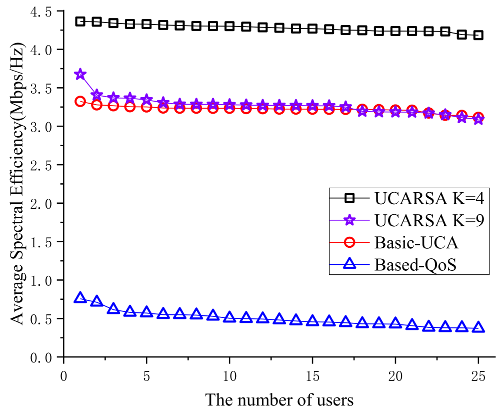

Fig. 8. Average spectral efficiency performance. FOV = 60°.

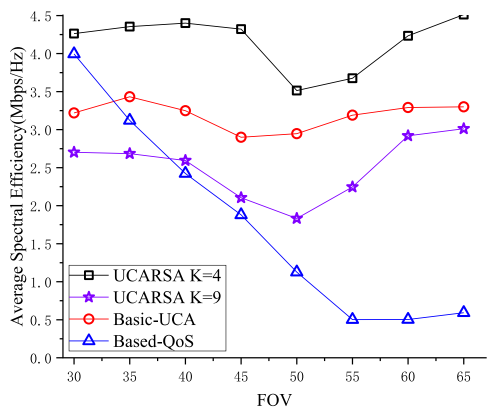

Fig. 9. Average spectral efficiency performance. $N_u = 25$.

is small, and the edge user prefers to access VLC AP with the lighter loads when FOV is large. All of users are associated with a VC instead of a certain AP, thus UCARSA $K = 4$ obtains the highest STP. However, the STP of UCARSA $K = 9$ is less than Basic-UCA with the FOV increasing, because the size of VC in UCARSA $K = 9$ is smaller than Basic-UCA, which results the reduction of the user rate.

Fig. 8 shows that ASE of different algorithms are decreasing slowly as the increasing number of users. Based-QoS transmits signals in the same frequency band and IM is not considered in the accessing process, which causes severe ICI and poor ASE performance. The spectrum allocation is performed in UCARSA before associating with users to avoid the bad influence of ICI and make the spectrum used effectively. Especially, UCARSA $K = 4$ obtains the highest ASE. The ASE of UCARSA $K = 9$ as low as Basic-UCA, because the effective bandwidth allocated to users is reduced when $K = 9$.

Fig. 9 shows the ASE of different algorithms as a function of FOV. The ASE of Based-QoS decreases rapidly with FOV increasing, because IM is not achieved in Based-QoS. Due to achieving IM at the transmitter, Basic-UCA and UCARSA $K = 9$ obtain the higher ASE and they are less affected by the change of FOV. UCARSA $K = 4$ has the best ASE performance. When FOV = 50°, the spectrum allocation tends to be performed in UCARSA. However, the interference becomes strong extremely when FOV > 50°, and the spectrum allocation has gradually become more effective for eliminating interference. Besides, the ASE of UCARSA $K = 4$ picks up to the highest level thanks to the reasonable spectrum allocation. In addition, the ASE of UCARSA $K = 9$ is less

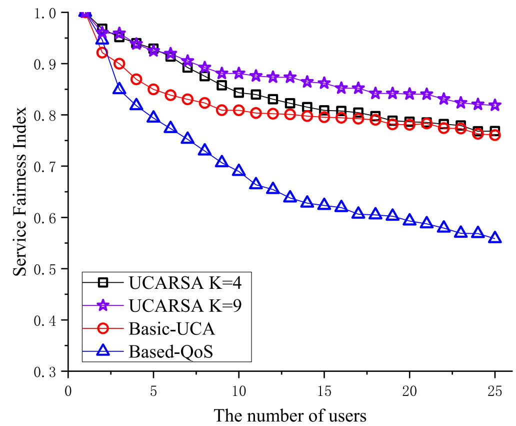

Fig. 10. Service fairness index performance. FOV = 60°.

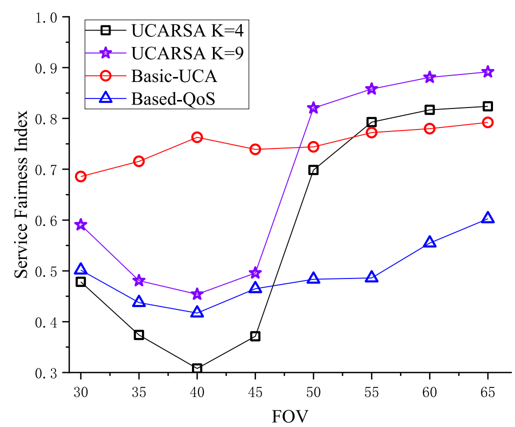

Fig. 11. Service fairness index performance. $N_u = 25$.

than ASE of UCARSA $K = 4$, because the bigger number of frequency bands results the reduction of effective bandwidth allocated to users.

Fig. 10 shows that SFI of different algorithms is decreasing obviously as the increasing number of users. When the number of users increases, the rate difference between users becomes large in Based-QoS. There is a little difference in user rates of Basic-UCA and UCARSA thanks to their VC construction and the decline of SFI is gentle relatively. When the number of users increases, the frequency band of each AP can be allocated reasonably according to different requirement of the data rate and UCARSA $K = 9$ obtains the best SFI.

Fig. 11 shows the SFI of different algorithms as a function of FOV. When FOV is the smallest, the number of the user accessing into the AP is balanced, so the user rates are similar. When FOV = 40°, a small number of edge users are affected by ICI, which results in the rate difference between the central users and the edge users. When FOV = 45°, the number of edge user increases, whose rates are generally lost. So that the user rate difference slightly decreases. However, when FOV = 50°, the spectrum allocation and VC construction of UCARSA are executed. Therefore, the overall rate of users is improved and the different user rates are more balanced again. Basic-UCA does not implement spectrum allocation, so the SFI is far less than UCARSA when FOV>45°. Basic-QoS is based on the user experience to select APs, so the SFI is high and it is rising slowly. In addition, the SFI of UCARSA $K = 9$ is higher than the SFI of UCARSA $K = 4$, because the bigger number of frequency bands results the reduction of the user rate difference.

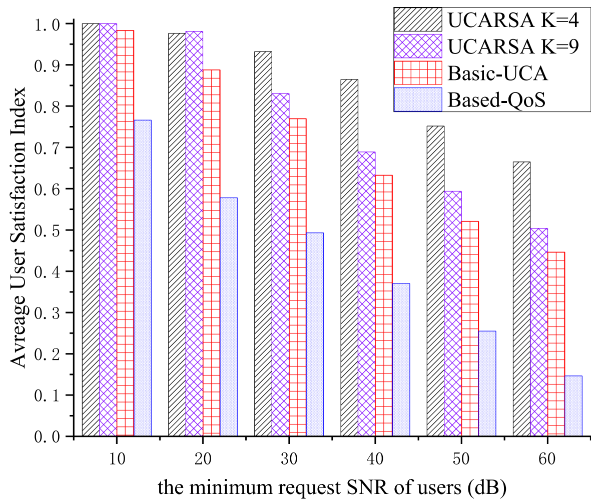

Fig. 12. Average user satisfaction index performance. $N_u = 25$, FOV $= 60°$.

Fig. 12 shows the performance of different algorithms in terms of ASI. With the addition of the minimum SNR requirement of the user, the performance of ASI decreases. The proposed UCARSA obtains the better ASI, because it achieves the interference eliminating and the user rate is high enough. The ASI of UCARSA $K = 4$ is higher than UCARSA $K = 9$, because many users obtain the higher data rate at the same SNR requirement when $K = 4$. It is difficult for Based-QoS to reach the expected user rate under the same SNR requirement because of its traditional association. Without limiting the size of VC, the actual achievable user rate in Basic-UCA is difficult to reach its required minimum rate.

5. Conclusion

Aiming at the problem of multi-access point selection for users in indoor VLC-WIFI heterogeneous networks, a user-centric access scheme based on interference management is proposed in this paper, which is expressed as the UCARSA algorithm specifically. When the FOV angle is large, the UCARSA algorithm performs spectrum allocation to eliminate the negative effects of ICI, so that the ASE obtains the promotion extremely. The virtual community is constructed for user to improve STP and SFI. The UCARSA algorithm not only improves system performance significantly, but also supports the mobility management of users in the heterogeneous networks.

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