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Resource Allocation Approach for Hybrid Cognitive Visible Light Communication

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Abstract: **Visible Light Communication (VLC) is now seen as a promising and powerful communication paradigm that provides separate facilities such as fast data communication, safe data communication, and high data rate wireless communication rather than radiofrequency, due to the worldwide demand for wireless technology. Cognitive radio can create a communication that can look across the spectrum, detects which is freely accessible and enforce user-to-user communication. Multi-cell cognitive visible light communication is suggested to enhance spectral efficiency. The strategy to the cognitive method is useful in strengthening the cell edge user's achievable sum rate based on LED switching status. The Cognitive-VLC multi-cell model involves all primary and secondary users (SUs), who are defined regarding the participants' service needs. Spectrum sensing is used to determine the user requirement. It is a critical feature of cognitive radio to protect designated users from harm associated and to classify usable spectrum for better spectrum use. Sensing results are evaluated to determine which scheduling scheme to implement. A flexible hybrid underlay/overlay scheduling method is also adapted to serve various users to enhance spectral performance. Under various user scheduling schemes, the cell edge users ' sum-rate and spectral effectiveness were evaluated.**

Keywords: Cognitive Radio, Visible Light Communication, Overlay/Underlay Spectrum Access, Resource Allocation.

I. INTRODUCTION

Wireless technology development has brought tremendous demand to the spectrum. There is limited availability of radio frequencies which is not sufficient for the development of wireless technology or otherwise most of the moment the spectrum is idle. The challenge occurred due to spectrum shortage and inactive spectrum has led to the establishment of visible light communication. In VLC, the spectrum can be used effectively and in predominant condition can also sustain effective communication [1].

Cognitive radio can create a communication capable of looking across the spectrum, detecting what is freely accessible and implementing communication between the two end users. It is an intelligent technology that automatically detects accessible channels in the spectrum, enables transmission and receiver parameters to be changed and enables transmission in a defined spectrum. The information is transferred via light rays in VLC, and the receiver only receives messages within a short distance. It is performed with optical components like LED. In terms of velocity, flexibility, usability and safety, this form of communication benefits wireless systems. As a natural source of energy, VLC is used to replace radio frequencies with visible light frequencies and cannot be applied to the use of LED lighting. This may also be one of the greenest and most environmentally friendly technologies owing primarily to elevated energy effectiveness. Cognitive visible light contact is emerging as a potential solution for overcrowded radio frequencies [2]. Secondary users in wireless applications can consider sharing the spectrum with primary users (PUs) in cognitive radio networks if they follow a particular protocol. [3]. The coverage area of each access point is split into two fields, serving primary and secondary users, respectively, in an OFDMA-based VLC network. Maximizing the region spectral performance when meeting the criteria for visibility, mobility and handover is accomplished by using the appropriate zone radius and subcarrier distribution. Another cognitive multi-cell VLC motivated by radio was considered in which users are designed being the PUs with intense delay constraints and service requirements. Users with fewer specifications, on the other hand, are designated as SUs. The SUs use dynamic sub-channel and energy sharing to distribute the PU sub-channels through overlay as well as underlay spectrum access protocols [4].

The demand for spectrum and high data rate wireless services is increasing due to multimedia applications, which presents a significant challenge for mobile networks. As most data communication nowadays takes place indoors improving the quality of wireless service for indoor users is, therefore, a considerable problem. Cognitive and Visible Light Communications (VLC) technology can be a good way to boost the quality of indoor wireless communication [2]. In this, the primary user and secondary users are defined based on users' location and also on various service requirements [5]. They further proposed underlay/overlay power allocation approach. However, they failed to account for the light-reflective effects of the room's ceiling and walls.

The proposed system aims to communicate point-to-point over visible light and illuminate the region where the transmission is designed. The transmission must be sufficiently stable to allow secure communication. The distance and speed at which information can be transmitted are also parameters that are taken into consideration as they may limit their applications. Sum rate analysis Maximizing the user's transmission rate. Area spectral efficiency analysis to improve the indoor communication system's spectral efficiency.

The following is a breakdown of the paper's structure. The related works are described in section 2, and the system model and implementation are explained in detail in section 3. The experimental findings are explained in Section 4 and Section 5 brings the work to a conclusion.

II. LITERATURE REVIEW

Hanaa Marshoud et al. [6] suggested a model for providing high data rates to non-orthogonal multiple access in a downlink network in an indoor environment using VLC. NOMA method is specifically used to raise the system's information rate where the modulation bandwidth is restricted in visible light communication. Multiple LEDs are regarded indoor with slightly overlapping beams formed by neighboring LEDs. Thus users situated at the cell border can obtain information streams from two adjacent LEDs that maximize the edge users ' diversity gain in the cell—the central control unit to which the user's location and related gain are shared. When a user changes their position, data is updated to CCU appropriately Gain power distribution is used to allocate power to the users in the LED coverage. Compared to other methods of power distribution, this allocation technique improves system efficiency. FOV tuning proves better efficiency among those tuning analyzes. FOV may also improve user accommodation at the same moment.

Hossein Kazemi and Harald Haas [7] suggested downlink collaboration for the optical attocell network to improve spectral efficiency. The light propagation model for the indoor VLC channel is line-of-sight (LOS). The LED serves as the base station, while the photodiode receiver serves as the user's equipment. The non-orthogonal amplify and forward protocol is used to implement cooperative downlink transmission, and one or more adjacent Base Stations (BS) which participates. The information from the User Equipment (UE) is divided into two parts. During the first time slot, the BS sends the first component directly to the UE and simultaneously to the chosen relay BSs. During the second time slot, the relay BSs enhance the noisy signal and resends it to the UE, whilst second element is transmitted to the UE by the BS. The efficiency is evaluated for different relay system. It implements half-frequency reuse and full frequency reuse. Higher spectral efficiency is provided by comparing both suitable maximum frequency reuse methods.

Marwan Hammouda et al. [8] suggest a cognitive indoor visible light communications (VLC) scheme. Through use of OFDMA methods, LED acts as an access point for main and secondary consumers in this model. Based on the region they are situated; users are distinguished primary and secondary users. To provide mobility, handover and illumination, lightning cell design was introduced. Thus, the cell offers high ASE.

N. Varshney and A. K. Jagannatham [9] implemented Underlay cognitive radio in a free-space optical network. The secondary user communicates without interference with the target node through the relay node. To quantify the efficiency of the suggested system obtained from closed-form outage probability and expressions of ergodic ability and to demonstrate that secondary user efficiency can be improved in the presence of light. The System efficiency indicates that the SU's transmission capability depends on the weather and the number of relays in the system.

To obtain high information rates in visible light various input and various output techniques, Chen Chen et al., [10] are implemented. Non-orthogonal frequency division multiplexing and imaging angle diversity techniques are used to provide user coverage. It has been shown that a MIMO-VLC system's illumination coverage is primarily influenced by the LED positioning and the LED's peak luminous intensity when compared to the square and hexagon LED.

For visible light communication, orthogonal frequency division multiplexing access has been introduced by Jiun-Yu Sung et al., [11] The presented VLC system could take advantage of the LED sources' bandwidth. At any point in the VLC scheme, capacity can be assured. The sharp SNIR differentiation at the boundaries of various sub-regions can easily be used to track position. Switching delay minimized by the OFDMA mechanism.

In a downlink case, Zhiguo Ding et al. [12] investigated the use of non-orthogonal multiple access with randomly installed users. The developed system demonstrates that NOMA can achieve greater efficiency with regard to ergodic sum values and allotted power.

Thanh V. Pham et al., [13] have suggested multi-cell visible light technologies with multiple users using a coordinated preceding between cells. The signal obtained via a user in each multi-cell scheme that serves multiple users can be significantly deteriorated not only through interference induced by signals meant for other cell users, but also by other cell signals. A coordinated precoding method is suggested to remove these interferences, which enables cooperation between VLC cells. In the proposed system, LED arrays within a cell can coordinate with neighboring cell LED arrays to cancel inter-cell interference.

Here the main aim of Vasilis K. Papanikolaou et al., [14] was to explore a composite VLC/RF network based on the premise that both subsystems are supported by a single, low-capacity backhaul. Due to the inherent discrepancies in between two networks, the resource distribution of the resultant hybrid network is optimized to maximize users' feasible data rates while maintaining customer equity. In order to measure the effect of channel inaccuracies, the case of incomplete CSI is considered. The effectiveness of the proposed study is demonstrated by simulation results, which provides insights on the entire system's efficiency and reliability.

Mohammad A. Dastgheib et al., [15] established an efficient algorithm to resolve issues with relative fairness objectives. Here the subsequent data rate of users was estimated and incorporated into the optimization problem by predicting the existence of a positioning system and leveraging the stationary characteristics of the indoor VLC channel. To improve the overall efficiency of VLC networks the user mobility perception was used. Our proposed method is successful, and it also eliminates the need for additional argmax at each iteration, according to the simulation results.

In wireless communication, Huaqing Zhang et al., [16] integrated VLC and D2D to offload CSP data flow. Instead of distributive operations, a standardized game is used to evaluate the strategies for the Visible Light Contact Service Provider (VLCSP), the Cellular Service Provider (CSP), and all relays (RUs). Initially, the VLCSP shows size of the data packet and the CSP calculates the value for its licensed spectrum based on this detail. Then, using the above-mentioned distributive operations, the data rate in the accessible data transmission routes is determined. Every RUs inside this chosen direction are included in the Nash equilibrium of such a graphical game. Depending on the Nash equilibrium result, the Stackelberg equilibrium is reached among the pairs VLCSP and CSP; CSP and RUs; and VLCSP and RUs. Simulations demonstrate the accuracy of the study and the high efficiency of the methods suggested.

A unique description of the Energy Efficiency (EE) in VLC scheme is proposed in this paper by E. Li et al., [17] and using this the EE-SE tradeoff was being derived in a closed form. In regard to the SE with main transport protocol, this very tradeoff has been provided like an EE function. The suggested EE-SE tradeoff of VLC systems was therefore confirmed by simulation results and also concluded that the best EE can be attained. The transmission condition criteria can have a big impact on the EE and SE's results. Hence the conceptual outcomes of this paper could be utilized to develop a realistic and effective VLC system.

Relevant to a specific geometrical structure of the cell region, Marwan Hammoudaa et al., [18] have provided a resource assigning methodology that is also effective in over powering inter-cell interruption using orthogonal frequency division multiple access (OFDMA). It is recommended to divide cell coverage as two nonoverlapping zones and using a two-phase resource distribution methodology, with each phase referring to a distinct level of resource distribution, which includes zone and user levels. At first both zones are described related to physical area and resource allocation, then the effect of lighting requirements are considered. Validation of scheme's output in the form of region spectral efficiency and equity among the two zones are done using simulation models.

Mugunthan, S. R. [19] Described the challenges and limitations of Li-Fi on smart communications.

III. SYSTEM MODEL AND IMPLEMENTATION

3.1 Overview

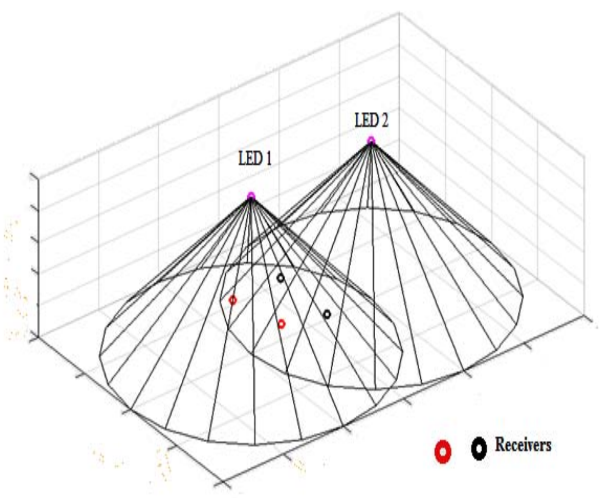

Figure 1. Illustrations of the system model

For the analysis, a scheme of cognitive visible light communication is regarded. An indoor system with various users of two LEDs is considered. It is regarded as a tiny indoor environment with 2 LED light sources connected to the roof. LEDs are positioned on the LED1 = [xt1, yt1, zt1] grid, LED2 = [xt2, yt2, zt2] are the LED coordinates. The 1st LED is presumed to illuminate a certain ground plane coverage region, as shown in Fig.1. The PD as the receiver is deployed on a horizontal plane, [xr1, yr1, zr1],[xr2, yr2, zr2],[xr3, yr3, zr3],[xr4, yr4, zr4] of the four receivers respectively.

Initially check for ON or OFF state of LEDs. Assume that either LED is ON then users of that LED are deemed approved users or main users. And other users are regarded as unauthorized users or secondary users in that region of overlap. The primary user's channel condition is detected.

Scenario 1: The primary user is considered to be active. The secondary user then transmits at the lower energy without interfering.

Scenario 2: It is decided that the primary consumer is involved. The secondary user sends equal power that is assigned to the secondary user. The hybrid model is shown when these two scenarios is changed for each count value depending on availability. Then the overall sum-rate and spectral efficiency is calculated.

a. Implementation of the proposed model

The proposed model is implemented by using Matlab. Field of view, also called the **viewing angle,** is a solid angle of an LED through which light is sensitive. Field of view is an area where light can pass through. It is a visible area. Field of view will cause more user to get accommodated in that visible area. It is measured in degree. It will give less information about where precisely a user is present at edges of the angle.

Field of view can be broad or narrow-angle based on the manufacture of LED. If the field of view is wide, more user can be accommodated, and the spectral efficiency can be maximized. If the field of view is narrow less, user can only be accommodated, and the spectral efficiency will be minimized.

LEDs are built with outstanding efficiency for indoor illumination, thanks to the quick advancement of solid-state lighting technology. The ideal Lambertian optical model for LEDs is one in which the rate of propagation is equivalent to the cosine of angle of view. The number of paths in the VLC channel expands as a result of scattering induced by several light sources.

Lambertian order defines a Lambertian distribution(m). The VLC channel now has a multipath setting thanks to this distribution. The Lambertian order (m) is defined as follows:

$$m = -\frac{\log(2)}{\log(\cos(FOV))} \quad (1)$$

Channel DC gain is the ratio between the output to input power. The direct current (DC) gain of a VLC channel is expressed as [14] in a VLC device, supposing almost every LED maintains Lambertian radiation pattern and considering just the line of sight components (LOS). (pal four)

$$H = \frac{(m+1)\, cos^{m}(\varphi) A \cos(\theta)}{2\pi d^2} \quad (2)$$

Where m denotes Lambertian order and φ is the LED's viewing angle, A denotes the photodiode field, d denotes the distance between the corresponding LED & photodiode and θ denotes the incident angle.

Noise in communication system refers to the undesired disturbance that masks the transmitted signal. It is the limiting factor the system performance. The noise channel is assumed to be an AWGN (Additive White Gaussian Noise) channel.

Shot noise dominates transmission quality in the optical channel, while thermal noise is represented by

$$\sigma^2 total = \sigma^2 shot + \sigma^2 thermal \quad (3)$$

Short noise arises due to optical power fluctuation, occurring due *to* the discrete nature of photons in light. It is an essential source of noise in an optical device. It is expressed as

$$\sigma 2\ shot = 2qB(Pr + Ibg + I2) \quad (4)$$

Where q represents the electron's charge, B equals the noise's bandwidth, $I_{bg}$is the background, current$I_2$is the noise bandwidth factor

Thermal noise occurs due to the random motion of charge carriers. It is an essential source of noise in electronic circuits. It's given by

$$\sigma^2{}_{thermal} = \frac{8\pi k T_k}{G_{ol}} C_{pd} A_{pd} I_2 + \frac{16\pi^2 k T_k \eta}{g_m} C^2{}_{pd} A^2{}_{pd} I_3 B^3 \quad (5)$$

Two terms reflect feedback resistor noise and FET channel noise, respectively, in this equation. Where $T_k$is the absolute temperature, Gol is the open-loop voltage gain, Cpd is the photodiode's fixed capacitance per unit area, k is the Boltzmann's constant, $I_2$is the noise bandwidth factor, Bnoise bandwidth and $g_m$is the FET trans conductance.

It's a technique used to distribute the total available power at the transmitter along the various channels. The power allocation policy for each user that can maximize the total spectral efficiency. Here the power allocation used is normalized the gain difference in power allocation method. This method of power allocation is based on the channel gain.

The VLC channel gain is solely determined by the distance between the user and the system. The goal is to implement cognitive technology in multiple LED scenarios for achieving the highest sum rate. Users are given different power assignments depending on their channel gains. [6]. The power allocation of various users is given by

$$\alpha = \frac{H_n - H_{(n+1)}}{H_n} \quad (6)$$

Where $\alpha$is the power allocation factor, Hn is the channel gain of the primary user and $H_{(n+1)}$ is the channel gain of the secondary user.

Underlay mode:

The primary user's power is determined by the channel gain in underlay mode, which is given by

$$P_{PU} = \alpha \quad (7)$$

The power given to the secondary user is determined by the channel gain and the power given to the primary user.

$$P_{SU} = \frac{1}{1+\alpha} * P_{pu} \quad (8)$$

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Overlay mode:

The channel gain determines how much power is allocated to the primary user and is given as

$$P_{pu} = \frac{1}{1+\alpha} \tag{9}$$

The power given to the secondary user is determined by the channel gain and the power given to the primary user.

$$P_{SU} = P_{pu} \tag{10}$$

The transmitting optical power and the optical channel gain are used to calculate the received optical power. It is determined as follows:

$$P_{rx} = H * P_{tx} \tag{11}$$

Where H is the optical dc gain and P_{tx}transmitted optical power.

Since the FOVs of two or more receivers may overlap, multiple detectors may acquire the desired signal for their serving cell at the same time. The ratio of obtained visible light power to noise is known as signal to noise. It is seen in the diagram below.

$$SNR = \frac{R*P_{rx}}{\sigma^2{}_{total}} \tag{12}$$

Where $P_{rx}$is the received signal power, R is the responsivity of the photodiodes the total noise variance. Sum rate defines the overall capacity that a system can achieve.

$$SumRate(R) = \frac{1}{2} B\ log_2(1 + SNR) \tag{13}$$

It is the optimum data rate per unit bandwidth of a device in a coverage area which is randomly placed. The unit is bits/s/Hz/m^2.A higher spectral means that the network can support more users. It is expressed as

$$ASE = \frac{R}{\pi B r^2} \tag{14}$$

Where R is the capacity of the cell, B is the bandwidth and r is the radius of the coverage area.

IV. RESULTS AND DISCUSSIONS

Sensing result is obtained to differentiate whether the user is authorized or unauthorized based on the switching condition of the LED. After differentiating the users, based on the user's service requirement mode of operation of the user is adopted and channels are used for the communication. Based on the bits generated by the users, users are differentiated as an authorized user or unauthorized user of 'ON' LED. Primarily, LED generates a bit and transmits to the user in the overlap region. On receiving the bits, the user of the respective LED generates the same bit as that of the transmitter.

Based on the bits generated, user are identified. The bit which caused the same bit as of LED is recognized as Primary user (PU). The bit which asynchronies with the bit generated by the LED are considered as the secondary user (SU). Thus the users are identified based on the bit generation.

After distinguishing the users, a user who needs spectrum access passes an access token to the LED. When LED receives a token, it sends it to the approved user. Now the authorized user based on its requirement for accessing the spectrum replies to the LED. This reply is forwarded to the requested user. Based on the user undergoes overlay and underlay mode. i.e. if the channel is busy underlay mode is chosen else overlay mode is selected.

TABLE 1 Key parameters for system simulation

PARAMETERS	VALUE
No of LEDs	2
No of receivers	4
Height of receiving plane	0.25 m
Responsivity of detector	0.53 A/W
The gain of the optical filter	0.9

Underlay Mode

When the channel is sensed as active, the users act in underlay mode that is both users uses the spectrum at the same time with less power that does not cause any interference to the authorized user.

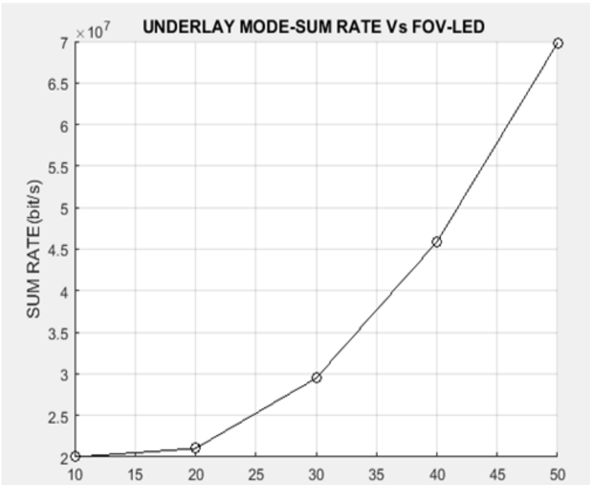

Figure 2 Underlay Mode- Sumrate VsFOV

Fig 2 shows that the value of sum-rate increases with respect to the field of view angle. This indicates that when the field of view angle is less, then user's accommodation is less hence signal to the user is not reached correctly. Thus, at the lower view angle capacity of information reached to the user without loss is less.

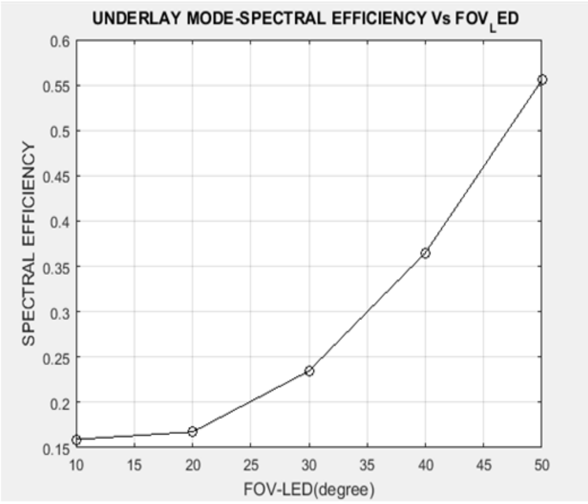

Figure 3. Underlay Mode- Spectral Efficiency VsFOV

Spectral Efficiency Vs Fov

Fig 3 shows that the value of spectral efficiency gradually increases with respect to the field of view angle. This indicates that when the field of view angle is more, then user accommodation is more hence spectrum is effectively used, achieving higher area spectral efficiency.

Overlay mode

When the channel is sensed as inactive, the users act in overlay mode that is the secondary users uses the spectrum only in the absence of authorized user with equal power that is allocated to the authorized user.

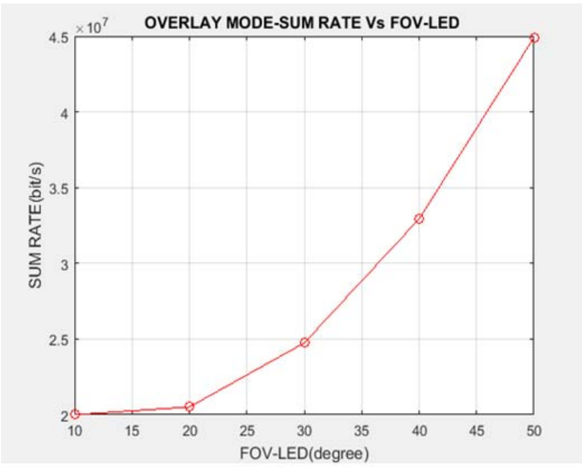

Figure 4 Overlay Mode- Sum rate Vs FOV

The value of the sum-rate steadily increases corresponding to the field of view angle, as shown in Fig 4. This indicates that when the field of view angle is more, then it covers more users. Hence the signal is reached to all the users without any loss.

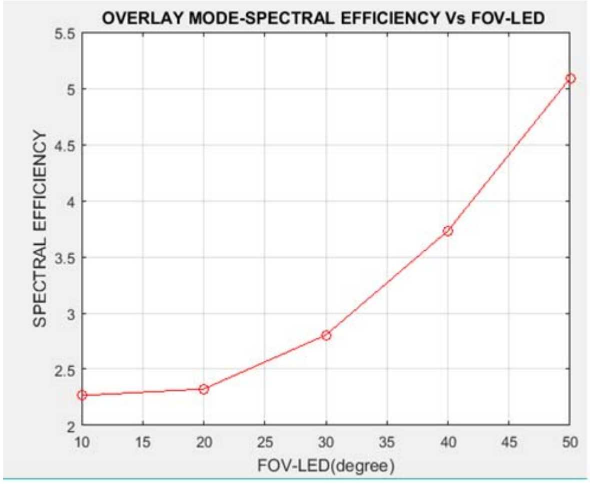

Figure 5 Overlay Mode -Spectral Efficiency Vs FOV

Spectral Efficiency Vs Fov

Fig 5 shows that with respect to the field of view angle, the area spectral efficiency achieved is higher. This indicates that when the field of view angle is less then users accommodation is less hence spectrum cannot be effectively used, but in the case of the higher field of view angle it is vice versa. Thus, at the lower view angle, spectral efficiency is less.

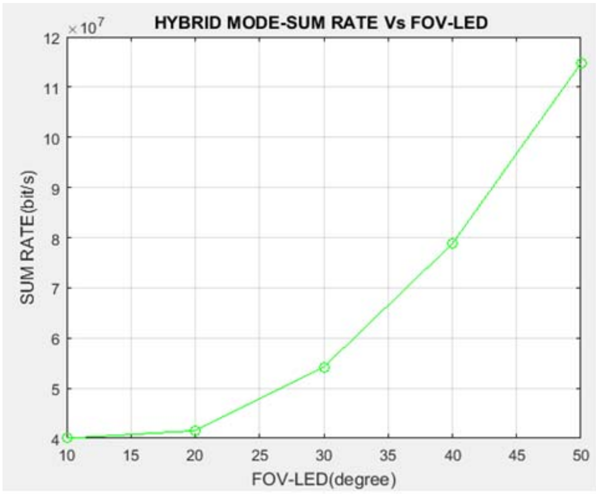

Figure 6 Hybrid Mode- Sum rate Vs FOV

Hybrid Mode

The adaptability between the underlay mode and overlay mode is a hybrid mode where every time slots the spectrum is sensed and mode is shifted. The total sum rate of the device is depicted in Figure 6. It depicts the system's total rate when both modes are active. Thus, the sum rate is higher and increasing at the higher field of view angle.

Spectral Efficiency Vs Fov

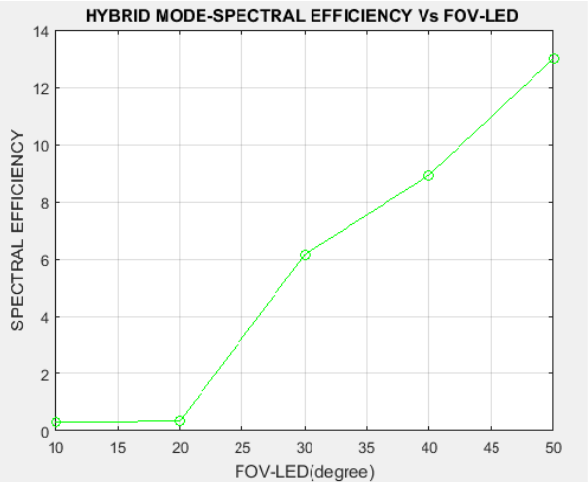

Figure 7 Hybrid Mode -Spectral Efficiency Vs FOV

Figure 7 depicts the system's overall spectral efficiency in hybrid mode. It indicates that the system's spectral efficiency is higher and increasing when it operates in both modes.

Comparison of Sumrate

Fig 8 shows that sum-rate of the hybrid mode is high when compared to the underlay and overlay mode. Since the power assigned to the secondary user is increased in overlay mode compared to underlay mode, the sum-rate of the overlay mode is higher.

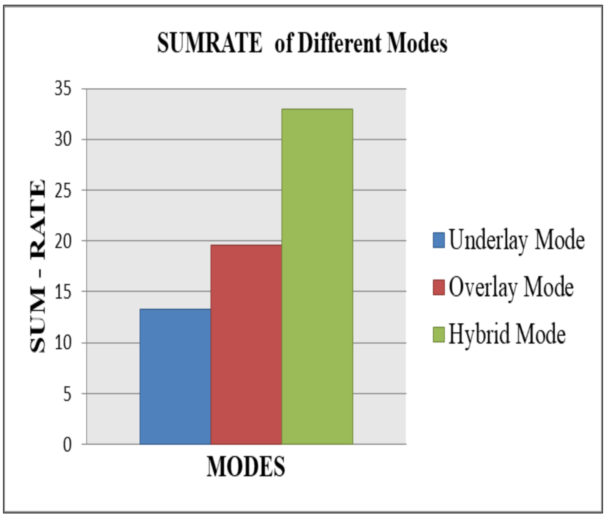

Figure 8 Comparison of SUMRATE

Comparison Of ASE

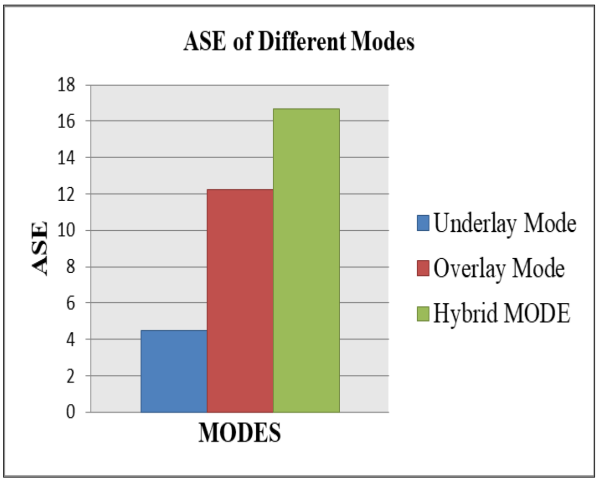

Figure 9 Comparison of ASE

Fig 9 shows that area spectral efficiency of the hybrid mode is high when compared to the underlay and overlay mode. Since the power assigned to the secondary user is high in overlay mode compared to underlay mode, the spectral efficiency of the overlay mode is higher.

5. Conclusion

To maximize the spectral efficiency of VLC systems while taking into account the optical limitations of VLC systems, a multi-cell cognitive VLC model with a flexible hybrid underlay/overlay power assigning strategy was suggested in this paper. In this paper, a downlink multiuser VLC circumstance with static users and cognitive transmission is used, and various device scheduling strategies based on spectrum availability are examined. Then the simulation of the sum-rate and area spectral efficiency is carried by the suitable simulation tool. Meanwhile, the user scheduling procedure with the higher FOV angle attains a higher sum-rate efficiency, demonstrating the influence of FOVs on device activity. When the sum rate of three user scheduling schemes: underlay, overlay, and hybrid are compared under static power allocation, it can be shown that the sum rate is increased by increasing the angle of FOVs, by aiding the edge users to get their signals between both LEDs more conveniently. Simulation results shows that Hybrid system achieves high sum rate and spectral efficiency than overlay and underlay model. This FOVs as an important parameter that will produce the best results because it allows each user to optimize reception based on their location. Within the room, the effects of reflection and transmission from either the ceiling or walls can be observed. NLOS, in addition to mobile users, is a critical problem that has the potential to dramatically degrade device performance.

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