Light Beam Allocation Algorithm for Eliminating Interference in Visible Light Communications

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***Abstract* – In this paper, we present a model of visible light communication (VLC) systems which exploit light beams for downlink transmission. A calculation method is proposed for light beam configuration which guarantees no blind areas in the whole VLC coverage while minimizing the number of light beams. As a major contribution in this paper, a light beam allocation algorithm is proposed which aims to eliminate interferences between inter VLC Access Points (inter-APs) by using information of incoming data queue length and co-channel interference (CCI) conditions to decide which VLC beams are used for transmitting data to appropriate user equipments (UEs). By deploying the proposed algorithm, CCI can be eliminated because noise-effected regions and noise-free regions can be separated. Performance of the novel light beam allocation algorithm is analyzed, evaluated and then compared with that of another light beam allocation method using the Round-Robin algorithm. Performance results show that there are significantly improvements in SINR, user throughput and packet delay parameters when deploying the proposed light beam allocation algorithm.**

Keywords – Visible Light Communications (VLC), Light Beam Configuration, Resource Allocation Algorithms.

I. INTRODUCTION

Visible light communications (VLC) has been proposed as a new communications technology for future mobile communications as an alternative solution for RF indoor communications systems. When providing VLC indoor communications, in order to eliminate co-channel interference from neighbor VLC access points (APs), light beams are proposed for VLC systems. In a light beam VLC system, LED-array transmitters are divided into small beams where each beam has a different beam direction angle and specific coverage area. There have been some researches related to configuration design such as optimizing configuration for handover in [3] or light beam configuration by using spatial light modulator [4]. However, there are some limitations on these designs, for example in [3], low spectral efficiency is achieved because there are large overlapped areas among neighbor APs. In [4], because there is only one beam used at a time, therefore, illumination task is not satisfied, the light is only concentrated on one small coverage around UEs. Beside the configuration designs, researches on resource allocation management are also interested in [5], [6]. An improvement on spectral usage is proposed in [5] by sending feedback information from UEs to APs. A neighboring AP that intends to reuse the reserved resource listens to the Busy Bust slot and infers the amount of CCI it could cause towards the UE that has reserved the resource to limit CCI caused to the active link to a threshold value. Although, APs know the CCI level, the restriction of this propose is the compromise between user throughput and SINR. The concept of multi-point joint transmission (JT) adapted to a VLC cellular network was proposed in [6]. However, a disadvantage of the approach is the requirement of synchronization among neighbor access points for cooperation. In the recent researches, light beam configuration, light beam allocation and CCI elimination have not been considered. To our best knowledge, these important functions are still open research challenges.

In this paper, a calculation method for light beam configuration is discussed. The method is used for calculating the minimum required number of light beams for guaranteeing that there will be no blind areas in the VLC network coverage. A light beam allocation algorithm are also proposed to increase performance of VLC systems by eliminating CCI, raising spectrum efficiency, removing the compromise between user throughput and SINR in [5]. These can be explained by applying light beam configuration cooperating with proposed resource allocation algorithm and demonstrated in system simulation section.

The paper is organized as follows. The calculation method for light beam configuration is presented in Section II. The light beam allocation algorithm in the light beam configuration is discussed in Section III. Simulation results are analyzed and evaluated in Section IV. Conclusions of the paper are given in the last section V.

II. LIGHT BEAM CONFIGURATION METHOD

In this paper, hybrid Light of Sight (LoS) links [7] among APs and UEs are used to replace for conventional non-directed LoS links. Advantages of using hybrid LoS links are high power efficiency and the isolation of noise-effected and noise-free regions between neighbor APs, therefore, the effects of CCI can be reduced. In order to ensure seamless connections between UEs and transmitters, light beam configuration must guarantee that any position in room must be covered by at least one transmitter for lighting. In optical wireless communications, because receivers have the fixed field of view angle (FOV), light beam configuration has to guarantee that UEs are able to receive signals from at least one AP. Another requirement is the minimum number of transmitters installed on ceiling to reduce the cost. The criteria of light beam configuration method are given below:

A. *Guaranteeing no blind areas in the coverage of one AP*

The light beam configuration method divides a LEDs array into beams in order to increase the emitting orientation of transmitters with a beam direction angle θ, a half power angle of beams $half_{beam}$. In the configuration method, each AP has N_b beams including one central beam and $N_b - 1$ surrounding beams which is found in section II-B, these beams have overlapped areas in order to ensure seamless connections. Each beam includes a group of LED chips which have the same optical power and half-power angle. The first requirement of the light beam design method is to provide no blind areas in the coverage of AP. That means all neighbor beams of the AP have to intersect to each other. Refer to Fig. 1, this requirement is expressed by mathematical relationship as follow:

$$MC \le R \qquad (1)$$

Where M is the first intersection point of two surrounding neighbor beams lied in the coverage of the central beam. *I1* and *I2* are central points of two surrounding neighbor beams as Fig. 1. R and C are radius and central point of central beam coverage at UE height, respectively as shown in Fig. 1.

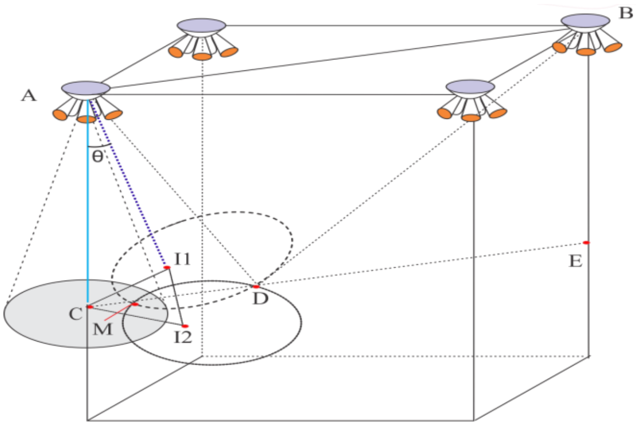

Fig. 1. Transmitter configuration

Solving the requirement (1), a set of equations is achieved as follow:

$$\begin{cases} 1-\cos(\theta) = \sin(\theta).\tan(half_{beam}) \\ \quad .\cos\left(\dfrac{2\pi}{N_b-1}\right).\left\{\sin\left(\dfrac{\pi}{N_b-1}\right)+\cos\left(\dfrac{\pi}{N_b-1}\right)\right\} \\ 1-\cos(\theta) = \tan(half_{beam}).\cos\left(\dfrac{\pi}{N_b-1}\right).\sin(\theta) \end{cases} \qquad (2)$$

Equations in (2) express constraint relationship among some parameters such as the half power angle of beams, the beam direction angle and the number of beams in one AP in order to ensure that there are no blind areas in the coverage of one AP.

B. *Guaranteeing no blind areas between neighbor APs*

The relationship among the number of APs, room dimensions, height of UEs h_{user} and the distribution of APs in room is presented as follows. Assume that room dimensions are $W \times L \times W$ (m^3) (Width, Length and Height), and UEs have horizontal signal reception plane with FOV.

In fact, transmitters can be located randomly or following certain layout e.g. hexagonal, rectangular and triangle layouts [6]. In this paper, the rectangular distribution of transmitters is implemented for purposes of uniform lighting and providing seamless connections.

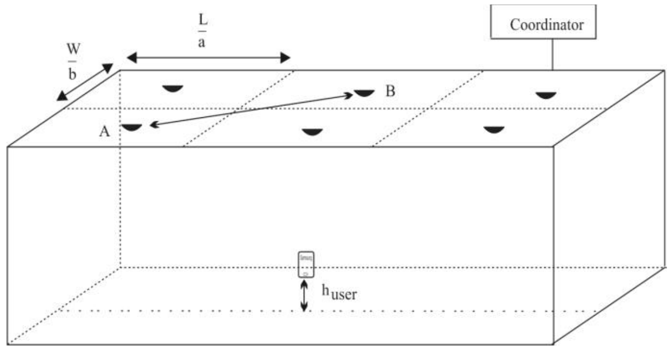

Fig. 2. APs configuration

Hence, the light beam configuration method first divides the length and width of the ceiling into **a** and **b** equal parts, respectively. ($a \times b$) identical rectangular cells with the length of L/a (m) and the width of W/b (m) are shown in Fig. 2. Each rectangular cell is then mounted by a LED lamps at the center. The Aps configuration has to ensure the illumination in range of 300-1500 lx by International Standard Organization (ISO) at all points in room [8] for providing high SINR and high received signal power in order to achieve high communication performance and no bind among neighbor APs.

The matrix expression of APs in room is given as follow:

$$\begin{bmatrix} AP_{1,1} & \cdots & AP_{a,1} \\ \vdots & \ddots & \vdots \\ AP_{b,1} & \cdots & AP_{b,a} \end{bmatrix}$$

Therefore, the set of APs in room is descripted as:

$$APs = \{AP_{i,j}\}, \; i \in \{1,...,b\}, \; j \in \{1,...,a\}$$

Each $AP_{i,j}$ has N_b beams depicted as follow:

$$Beams = \{b_x^{i,j}\}, \quad x \in \{0,..., N_b - 1\}$$

Where i and j are indexes of AP in the AP's matrix.

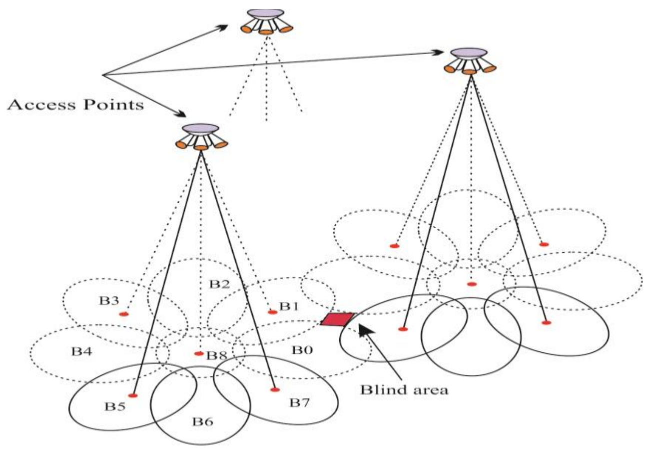

Fig. 3. Blind area between two APs illustrated by the dark figure

An example of blind areas shown in Fig. 3. Refer to Fig. 1, the requirement of no blind areas is expressed as follow:

$$CD \geq \frac{CE}{2} \quad (3)$$

Where D is the second intersection point of two surrounding neighbor beams, CE is maximum distance between two APs, CD is distance between point C and point D as Fig. 1.

In this paper, LEDs YZ-WS5N40N [9] with half power angle 20^0 are used, therefore $half_{beam}$ is 20^o. Solving the equation 2, the optimal number of beams in one AP equal to 9 is achieved and the beam direction angle θ is less than or equal 37.25^0.

Relationship (3) is calculated and then we get the below relationship:

$$\left(\frac{L}{a}\right)^2 + \left(\frac{W}{b}\right)^2 \leq 13.81 \quad (4)$$

In this paper, FOV is defined as the full acceptance angle at receiver side. To ensure that there is always at least one transmitter in the received signal region of UE, the method expresses the constraint relationship of FOV angle, distance between AP and UE and maximum distance between two APs. This condition needs to express as:

$$\tan(FOV).(H - h_{user}) \geq \frac{AB}{2} \quad (5)$$

Where H and h_{user} are the height of room and the height of UEs respectively.

C. Downlink channels

VLC downlink channels using wavelengths in visible light region include two main functions. First, it provides essential light source for daily life. Second, VLC is a green technology [10] providing high speed downlink access in indoor environments. In this paper, an OFDM wireless multiple access mechanism for downlink channel is used in order to increase spectral efficiency where bandwidth of system is divided into N_{sc} subcarriers. The available OFDMA subcarriers are grouped in contiguous blocks made up of n_{sc} subcarriers and n_{os} OFDM symbols [5] which form resource units (RU). Suppose that, each AP has a group of RUs as followed:

$$RUs = \{RU_x\}, \quad x \in \{1, ..., N_{ru}\}$$

Where N_{ru} is number of RUs in one AP.

The baseband symbols are modulated into an OFDM symbol using Inverse Discrete Fourier Transform (IDFT) where incoming bit stream is converted from serial to parallel and then mapping is implemented [11]. Output signal at LED is real and positive, therefore, Hermitian Symmetry block is added for converting to desired real signal and then converted into analog signal by digital to analog (D/A) converter. The LED transmits an optical signal whose intensity is directly proportional to the driving current (i.e. IDFT output). The analog signal transmitted by the LED is given by [12]

$$x_m = \frac{1}{\sqrt{N_{sc}}} \sum_{k=0}^{N_{sc}-1} X_k \exp\left(\frac{j2\pi km}{N_{sc}}\right) \quad (6)$$

Where X_k is data symbol transmitted on subcarrier k, m is sample index or time index

The signal obtained after modulation x_m is proportion to transmitted optical power, then optical signal is propagated through wireless channel and impact on surface of Photo-detector by the strike of photons. The total channel gain by LOS channel is given by [8].

$$G = \begin{cases} \frac{(m+1).Aa}{2\pi D_d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi), & 0 < \psi < FOV \\ 0, & \psi > FOV \end{cases} \quad (7)$$

Where Aa is physical area of detector in Photodetector (PD). (D_d) is distance between transmitter and receiver, ψ is incident angle at receiver and $T_s(\psi)$ is gain of optical filter. The parameter m is the order of *Lambertian* emission, and is given by semi-angle at half illumination $half_{beam}$ of a LED chip [8].

The received optical signal is converted to current by using PD which has responsivity R_{pd}. Then current is changed to voltage by a trans-impedance amplifier (TIA) having gain R_F. The output signal of TIA is described as [5].

$$Y_t = R_F \left(R_{pd} G x_m + \omega_m \right) \quad (8)$$

Where (ω_m) is Gaussian noise created by shot noise and thermal noise of TIA transistor. The received signal is sampled, quantized and passed through FFT block in order to recover original signal.

N represents the electrical additive white Gaussian noise AWGN power on each subcarrier which is composed of shot noise and thermal noise. It is given by [5]

$$N = 2qR_{pd} P_{am} B_{sc} + \frac{4k_B T B_{sc}}{R_F} \quad (9)$$

Where $q = 1.6 \times 10^{-19} C$, ($P_{am}$) is the intensity of ambient light incident on the PD, (k_B) is the Boltzmann's constant, T is the absolute temperature and B_{sc} is the bandwidth of a subcarrier.

The signal power can be expressed as [5]:

$$E|Y|^2 = E\left[\left| R_F R_{pd} G X \right|^2 \right] \quad (10)$$

III. LIGHT BEAM ALLOCATION MANAGEMENT

A. Eliminating interference by applying the proposed light beam configuration method

1) CCI

In visible light communications, the coverage area of one AP is small. In order to ensure seamless connection, the coverage area of neighbor APs has to overlap to each other. These overlapped areas may cause CCI among APs if they allocate the same resource units. This reduces performance of the communication system due to the received SINR is decreased.

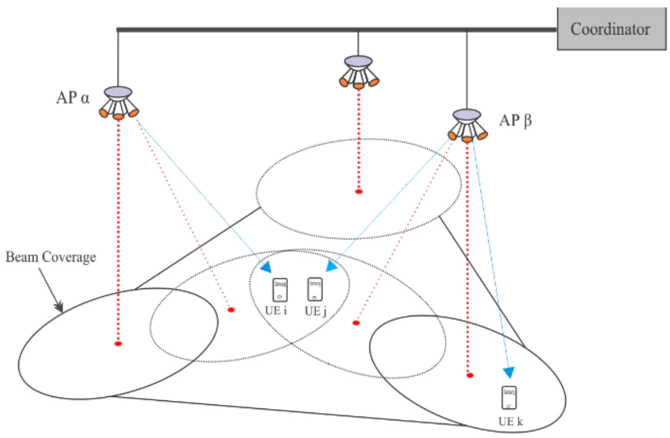

Fig. 4. Light beam configuration

In this part, CCI impacts in VLC systems are discussed in detail in order to make clear to highlight why the light beam configuration is better than the general configuration. This can be explained by splitting noise-effected and noise-free regions from neighbor APs.

Suppose that, UE i locates in the overlapped area and is managed by AP α as Fig. 4. UE j, together with UE k, is served by AP β and belong to different beams, and UE j is at the same overlapped area with UE i. Therefore, UE i and UE j are in noise region. In the first situation, if AP α and AP β allocate the same resource unit to UE i and UE j, this causes CCI to both of them, from AP α to UE j and from AP β to UE i. But in the second situation, if AP β allocates that resource unit to UE k (not the overlapped coverage with UE i of AP α) in light beam configuration, then CCI is eliminated (no interference in this situation). However, in general configuration, if we use that resource unit for UE k in AP β, there is also CCI from AP β to UE i being served by AP α. This is explained by beams which have smaller coverage and higher orientation than coverage of one AP.

2) SINR estimation

The channel gain is add subscripts of form $G_{\alpha^i,\mu}$ to distinguish desired and interference signals where the first subscript denotes the i^{th} beam belong to AP α and the second one denotes the UE. (X_{α^i}) expresses symbol transmitted by i^{th} beam belong to AP α. The received signal power and the interference power of an UE μ by a resource unit are expressed as follow:

$$R_{\mu}^{\alpha^i} = E\left[\left|Y^{des}\right|^2\right] = E\left[\left|R_F R_{pd} G_{\alpha^i,\mu} X_{\alpha^i}\right|^2\right] \quad (11)$$

$$I_{\mu} = \sum E\left[\left|Y^{\inf}\right|^2\right] = \sum_{\beta^j \in P} E\left[\left|R_F R_{pd} G_{\beta^j,\mu} X_{\beta^j}\right|^2\right] \quad (12)$$

Where (P) is the set of neighbor beams from neighbor APs allocated the same resource unit making CCI to active UE μ .

Signal to interference plus noise ratio (SINR) at UE μ is given by:

$$\xi_{\mu}^{\alpha^i} = \frac{\left(R_F R_{pd} G_{\alpha^i,\mu} \rho\right)^2}{\sum_{\beta^j \in P} \left(R_F R_{pd} G_{\beta^j,\mu} \rho\right)^2 + N} \quad (13)$$

Where (ρ^2) is electrical power on each subcarrier. The received signal has to achieve SINR higher than SINR threshold which is proportional to modulation format in order to decode signal with an acceptable low Bit Error Rate (BER). Generally, the voice signal has BER equal to 10^{-3} and the data signal has BER equal to 10^{-7} .

B. Analysis of the beam layout

Analyzing the beam layout based on coverage of beams in the proposed light beam configuration is discussed first. Each beam has a set of neighbor beams belonging to neighbor APs in which their coverages overlap to each other. In the system model, we assume that a beam can transmit data if its neighbor beams given in Table III are inactive.

An ($AP_{i,j}$) has a matrix of neighbor APs as follows:

$$\begin{bmatrix} AP_{i-1,j-1} & AP_{i-1,j} & AP_{i-1,j+1} \\ AP_{i,j-1} & AP_{i,j} & AP_{i,j+1} \\ AP_{i+1,j-1} & AP_{i+1,j} & AP_{i+1,j+1} \end{bmatrix}$$

Suppose that, $AP_{i,j}$ transmits beam $B_x^{i,j}$, where i and j are row and column indexes of AP in APs' matrix. In this light beam configuration method, the optimal number of beams equal to 9 is found in Section II–B, therefore $x \in \{0; \ldots; 8\}$ where set of beams is numbered as Fig. 3. The neighbor beams belong to neighbor APs having overlapped area to ($B_x^{i,j}$) is determined as follow:

TABLE III: ANALYSIS OF OVERLAPPED NEIGHBOR BEAMS

Beam	Neighbor Beams
$B_0^{i,j}$	$B_3^{i,j+1},\ B_4^{i,j+1},\ B_5^{i,j+1},\ B_8^{i,j+1}$
$B_1^{i,j}$	$B_3^{i,j+1},\ B_4^{i,j+1},\ B_5^{i-1,j+1},\ B_6^{i-1,j},\ B_7^{i-1,j}$
$B_2^{i,j}$	$B_5^{i-1,j}, B_6^{i-1,j}, B_7^{i-1,j}, B_8^{i-1,j}$
$B_3^{i,j}$	$B_1^{i,j-1}, B_0^{i,j-1}, B_5^{i-1,j}, B_6^{i-1,j}, B_7^{i-1,j-1}$
$B_4^{i,j}$	$B_0^{i,j-1}, B_1^{i,j-1}, B_7^{i,j-1}, B_8^{i,j-1}$
$B_5^{i,j}$	$B_7^{i,j-1}, B_0^{i,j-1}, B_1^{i+1,j-1}, B_2^{i+1,j}, B_3^{i+1,j}$
$B_6^{i,j}$	$B_1^{i+1,j}, B_2^{i+1,j}, B_3^{i+1,j}, B_8^{i+1,j}$
$B_7^{i,j}$	$B_4^{i,j+1}, B_5^{i,j+1}, B_1^{i+1,j}, B_2^{i+1,j}, B_3^{i+1,j+1}$
$B_8^{i,j}$	$B_0^{i,j-1}, B_4^{i,j+1}, B_6^{i-1,j}, B_2^{i+1,j}$

C. The light beam allocation algorithm

The functions of each elements shown in Fig. 4 in the system model are as following. The coordinator used to connect all APs, is responsible for operational control functions and decides which beam will be chosen for each AP to transmit in a timeslot of a frame. The coordinator uses information about the number of packets in queue of UEs and the CCI effects of neighbor beams from neighbor APs. For an AP, after receiving information about which beam is transmitted from Coordinator, the AP decides the resource allocation for UEs in that beam.

For details, in one timeslot, only one beam of each AP can transmit the data signal. This resource allocation algorithm expressed by Pseudo Code exploiting for eliminating co-channel interference based on light beam configuration has following steps:

At first, the list of APs in room is sorted in order to make priority in considering the choice of selected beam among APs. After that, List of beams of each AP is considered in order of index of that AP in List of APs. Then, the list of these beams is sorted to make priority among beams to determine which beam has larger queue length can be transmitted first. A beam then is selected based on condition in which there is no neighbor beam in Table III active. Information of selected beam is transmitted from Coordinator to APs, then RUs are allocated to active UEs in coverage of selected beam based on queue length of UEs. The algorithm prioritize UE which has maximum number packets in Buffer. If all packets in Buffer of users in selected beam is transmitted totally, the allocation RUs in that beam is terminated. Pseudo Code is implemented in each frame time duration and expressed as follow:

Where:

- $numberOfAP$ is the number of APs in the room
- $listBeam_{i,j}$ is the list of beams in $AP_{i,j}$
- $listAP$ is the list of APs in the room
- $listUser^{x}_{i,j}$ is list of UEs in beam x of $AP_{i,j}$
- $selectedBeam_{i,j}$ is the beam of $AP_{i,j}$ which can transmit data in some timeslot
- $frameSize$ is number of time slots in a frame
- $queueLength^{x}_{i,j}$ is the number of packets of all UEs in the beam x of $AP_{i,j}$
- $biggestBufferSize_{i,j}$ is the $queueLength^{x}_{i,j}$ of beam x of $AP_{i,j}$ which is the maximum value among beams in $listBeam_{i,j}$ at a time
- RU is the list of radio resource units.

```
for m ∈ [1 : frameSize] do
    // Make priority when selecting APs
    Create listAP in which the order of AP_{i,j} in the listAP is in increasing of
    biggestBufferSize_{i,j};
    // Select which beam can transmit in each AP
    for n ∈ [0 : (numberOfAP -1)] do
        AP_{i,j} = listAP [n];
        // Make priority when selecting beams
        Createt listBeam_{i,j} in which tThe order of b^x_{i,j} in the listBeam_{i,j} is
        in increasing of the queueLength^x_{i,j}
        for k ∈ [0 : ( N_b -1)] do
            if listBeam_{i,j} [k] hasall inactive neighbor beams (neighbor
            beams are matched from Table III)
                selectedBeam_{i,j} = listBeam_{i,j} [k];
                break;
            end if
        end for
    end for
    // Allocate RUs to UEs of the selected beam of each AP
    for n ∈ [0: ( numberOfAP - 1)] do
        AP_{i,j} = listAP[n];
        for k ∈ [0, ( N_ru - 1)] do
            RU[k] is assigned to the UE in the listUser^x_{i,j} which has
            maximum Buffer size (where beam x is the selectedBeam_{i,j} );
            Number of packets destined to the selected UE - -;
            if There is no packet in Buffer of the UE
                break;
            end if
        end for
    end for
end for
```

D. Round-Robin Resource Allocation Algorithm for light beam configuration.

This is considered as a conventional algorithm which select an AP and its beams for data transmission sequentially. In this method, CCI effects are ignored. After a selected beam is found, the RUs are allocated to UEs in the selected beam are carried out similarly to the RU allocation presented above.

IV. SIMULATION RESULTS

Simulation parameters is illustrated in Table IV where UEs are considered as two types: mobile UEs and stationary UEs. UEs having height of 1 (m) are uniformly distributed in coverage area of transmitters. The mobile UEs are created with their downlink connection, the calls are started whenever that UEs are born, then they move around the room until their lifetime is end. The lifetime of UEs follows exponential distributed with mean 180 seconds. New mobile and stationary UEs are created by Poisson process with the user arrival rate of 3 users/minute.

TABLE IV: SIMULATION PARAMETERS

Simulation Time	3600 (second)
Max Velocity of UE	0.3 (m/s)
Time Slot duration	0.001 (second)
Frame	4 (timeslot)
Bandwidth	20 (Mb)
Packet Size	2 (Kb)
Call Arrival Rate	3 (call/minute)
Number of APs	16
Half Power of Beam	20^0 [deg.]
Beam Directional Angle	37^0 [deg.]
Number of Beams in a AP	9

Room Length	10 [m]
Room Width	10 [m]
Room Height	3 [m]
User Height	1 [m]

In order to evaluate performance of the proposed light beam configuration and resource allocation algorithm, some performance metrics consisting of user throughput, packet delay time, SINR are used. Results are shown in form of CDF (cumulative distribution function) for these metrics.

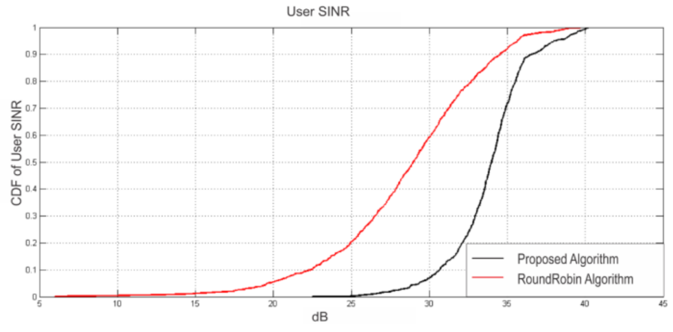

Fig. 5. SINR

The first performance metric is SINR shown in Fig. 6. By applying the Table III which determines the set of neighbor beams causing CCI to active beam, the proposed algorithm always chose beams to transmit which having all neighbor beams are inactive. Therefore, CCI effect can be eliminated. The simulation result shows a significant improvement of about 28% compared to the Round-Robin algorithm. There are 60% UEs achieve SINR lower than 30dB while proposed algorithm is only 9% in Fig. 6.

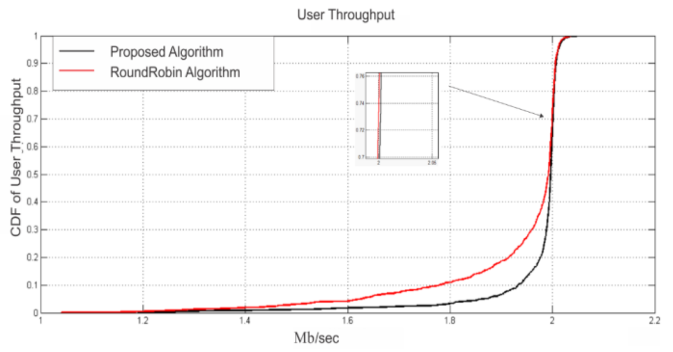

Fig. 6. User throughput

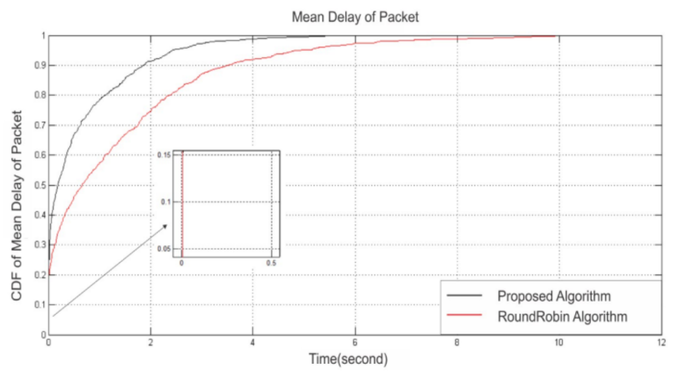

Fig. 7. Packet Delay Time

Simulation result in Fig. 7 shows that, there is a significant increase about 12.14% of proposed light beam allocation algorithm compared to conventional round-robin algorithm. Besides, the Fig. 8 shown about 20% of users have packet delay time smaller than 0.001 second by using Round-Robin algorithm, while the proposed algorithm is 40%. These simulation results can be explained by the proposed algorithm always selects beams which have the maximum queue length, but in Round-Robin algorithm, the beams are selected in sequential way. Therefore, the resource utilization of proposed light beam algorithm is better than Round-Robin algorithm.

V. CONCLUSION

This paper is carried out to establish light beam configuration with specific requirements in order to guarantee no bind area in whole coverage, minimize number of beams in one AP and aim to distinguish noise-effected regions and noise-free regions compared to general configuration. Besides, a light beam allocation algorithm is implemented for the proposed configuration based on CCI condition and queue length of UEs. The effectiveness of the proposed algorithm is compared with the Round-Robin algorithm, through simulation results, the proposed algorithm for light beam configuration significantly improve spectral utilization efficiency, simple system operation and the quality of service such as throughput and packet delay time. In the future works, in order to increase more spectrum utilization, the allocation of individual RU corresponding to beams of each AP is considered in detail, this meant that number of total RUs in one AP can be transmitted in different beams or more beams can be active at a time.

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