ORIGINAL PAPER

Hard link-switching scheme using pre-scanning for indoor VLC networks

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Abstract VLC has been accepted as a potential technology for deployment in indoor wireless networks in 5G. Use of efficient link switching scheme among VLC access points is critical in indoor environment to provide seamless connectivity to mobile users. This paper proposes a User Device (UD) based intermittent link switching based on hard link switching. This method is highly suitable for the indoor scenario where most of the fixtures and furniture remains unchanged. A Coordinator is employed in this method, that stores this information, thus, user is not required to search for the best transmitter when RSS is reduced to a threshold value as in conventional methods which cause substantial delay in switching process. Here, coordinator predicts the user position and allots best possible source for that position based on pre-scanned database and transfer the link to new source while releasing the old one by the time user reached that particular position. This method reduces the substantial delay time that occurs in switching process applied in conventional hard link switching. Simulation results show that the proposed scheme for indoor VLC System achieves the dual purpose of adequate illumination and mobility to user in considered indoor scenario.

Keywords Visible light Communication(VLC) · LED · Handover · Link switching · Received signal strength

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1 Introduction

Visible light communication (VLC) is one of the promising wireless communication technologies, which utilizes RGB or white LEDs to fulfill the dual requirement of communication and illumination in indoor scenario [1]. IEEE standard for Visible-light Personal Area Networks (VPANs) [2] has increased the research interest in developing and exploring techniques to achieve high data rates and reliable communication using common LEDs. Handover process of conventional wireless systems is referred as Link switching in VLC. Link switching is a critical parameter that deals with the signal degradation because of mobility of user device. Mobility can be categorized as; physical or logical. Physical mobility is change of position of user device due to the movement within a cell; while logical mobility refers to change in device communication link due to interference. Link switching techniques fall into two categories namely vertical and horizontal. Vertical handover refers to the automatic switching of datalink layer technology used to access the network to maintain desired QoS. There has been lot of efforts towards developing suitable handover mechanisms in vertical handover domain. [3–5]. However, horizontal handover when switching between light sources is required due to interference or change in receiver position has not garnered much attention. Nguyen et al. presented a novel RSS (Received signal Strength) prediction technique to reduce link switching delay; the presented technique also prevents unnecessary link switching [6]. Thai-Chien Bui et al. [7] presented a flexible link switching algorithm based on the received power by considering adaptive hysteresis margin.

In this paper, we propose a position prediction link switching algorithm for VLC configuration. Part II of the paper describes the related work; Part III gives background

734

Int. j. inf. tecnol. (April 2021) 13(2):733–740

and proposed System model. Part IV presents the link switching algorithm developed and conclusions are drawn in part V. Finally part VI presents future scope of the work.

2 Related work

Cisco system has predicted that by year 2022 approximately more than 80% of mobile traffic will appear indoor and 71% of internet traffic will be due to mobile data. [8], further Bao et al. simulated a hybrid VLC network and implemented an algorithm for efficient access and hand over control. Algorithm proposes a technique for subscriber to move to a VLC architecture and till the user is in VLC network, channel gain is higher as compared to standard value. [9] C. Jiang et al. work revealed load and traffic density follows temporary and spatial distribution law. [10] Issues related to limited availability of spectrum was explored by H. Haas et al., they published an article that explored possibilities that Li-Fi can offer radio frequency with increasing spectrum usage is following short of available bandwidth, shortage of spectrum has led to utilization of high frequency spectrum and Light fidelity is one of the potential area being explored. [11] Islim et al. presented how employing visible light for carrying signal can exploit, a lot of available unutilized optical spectrum, almost about 300 THz, ongoing studies reflect that the technology can achieve data rates as high as 10 Gbps [12]. D Karunatilaka et al. presented a model for integrating wireless networks with Li-Fi technologies,, here LED were employed to execute visible light communication, these were also tested and compared with other state of the art communication models. [13] P. H. Pathak et al. in 2015, explored issues and challenges with networking and communication with visible light and their potential for future applications of communication. Employing visible light communication would involve challenges of managing handover over heterogeneous networks, [14] D Q Hein et al. proposed techniques to manage seamless handover in VLC. [15] M. D. Soltani et al. simulated an algorithm for analyzing random orientation and user mobility in an Li-Fi scenario as the modified version to reflect channel occupancy to decrease collision probability. [16] The authors X. Zhou et al. developed an algorithm that works iteratively and emphasizes on power division, algorithm has two states, determining ideal power allocation and other is finding another AP for subscriber, algorithm is supposedly example of autonomous optimization. NOMA utilizes same frequency and time for communication with multiplexed power domain employing superposition coding with interference neutralization successively, the algorithm targets to explore cluster via game theory and merge and split technique to identify ideal user algorithm. [17] Recent

algorithm with interference handling technique suggest that bandwidth can be completely utilized, Li-Fi APs can support high volume of data with rates in Gbps [18].

3 Proposed system model

To establish the proposed method of link switching, an empty conference room was chosen, where LEDs were mounted at defined points. Dimensions of conference room are 12 m × 12 m and height 3 m, with 9 white LED -based lighting cell array (3 × 3) mounted on the room ceiling with LED coverage. The VLC indoor system adequately fulfills the illumination requirement since illumination is the primary function of LED lighting system. Further the system can support the device mobility with continuous data transmission.

This LED distribution provides the illumination level specified in ISO standard (illumination 300 ∼ 1500 lx in all the positions in the room) [19]. Thus, nine Access points are in positions (− 5; − 5;1.2), (− 5;5;1.2), (5; − 5;1.2), (5;5;1.2), (− 5;0;1.2), (5;0;1.2), (0; − 5;1.2), (0;5;1.2), and (0;0;1.2) as shown in Fig. 1. Movement of the mobile receiver device is assumed to be in a plane that is situated 1.8 m below the LED.

Further, each LED source produces a circular lighting field. Thus, each lighting cell has omnidirectional signal coverage with radius r meter and each LED Access Point (AP) transmits at data rate D bits/sec at the center of the cell and a MT receives data when it is inside a lighting cell. Given a mobile terminal crossing a lighting cell at constant speed v [m/s], the cell gain [bits] is the number of bits received by the mobile terminal during the time interval it spends while traversing crossing the lighting cell.
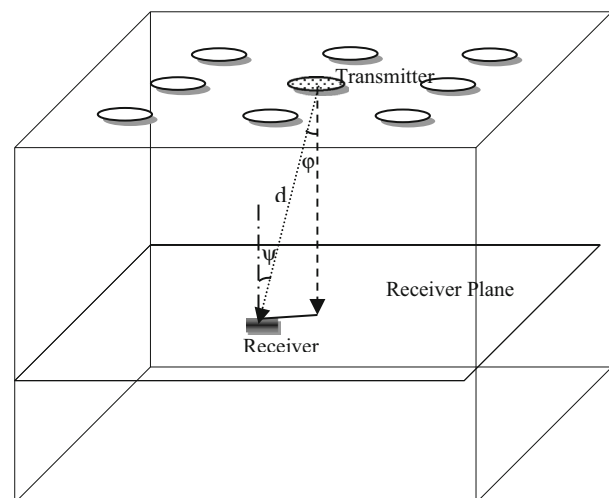

Fig. 1 3D scenario with 9 LEDS and a moving receiver

The parameters that need to be monitored for performance assessment of the VLC system are the transmitted optical power and luminous intensity. Horizontal luminous intensity is given by (1) at the receiver plane when distance between the detector surface and LED is d

$$I_{hor} = I(0)cos^{m_1}(\varphi)Id^2.\cos(\psi) \tag{1}$$

where, φ is irradiance angle with respect to the axis, normal to the transmitter surface and ψ is the incidence angle with respect to the axis, normal to the receiver plane. I (0) is the luminous intensity at the middle point just below the light, and m_1 is Lambertian emission order. If $T_s(\psi)$ is the filter transmission function, received power is

$$P_r = P_t \frac{(m_1 + 1)}{2\pi d^2} cos^{m_1}(\varphi).T_s(\psi).g(\psi).\cos(\psi) \tag{2}$$

A simple linear optical AWGN channel is considered with the optical transmitted power $P_t(t)$, impulse response $h(t)$ and signal independent additive noise $n(t)$ [20, 21].

Thus, VLC channel can be modeled as:

$$I_p(t) = RP_t \otimes h(t) + n(t) \tag{3}$$

With transmitted optical power

$$P_t = \lim_{T \to \infty} \frac{1}{T} \int_0^T P_i(t)dt P_i > 0 \tag{4}$$

Indoor scenario also requires consideration of reflections from the walls. Thus, total Received power is given by 5 [22]

$$P_r = \sum \{P_t H_d(0) + \int P_t dH_{ref}(0)\} \tag{5}$$

where $H_d(0)$ directed path and first reflection at the receiver is:

$$H_{ref} = \rho d_{LED}A_{wall}cos^{m_1}(\varphi_r)\cos(\alpha_{ir})\cos(\beta_{ir})T_s(\psi)g(\psi)\cos(\psi_r) \tag{6}$$

where, d_{LED} is the distance between the LEDs, ρ is reflectance factor, A_{wall} is reflective area of infinitely small region, α and β are the angle of irradiance to a reflective point and ψ_r is the angle of incidence at the reflective surface. 3 D plot of the received optical power at different points in the room is plotted in Fig. 2

4 Proposed link switching mechanism

Link switching techniques may be broadly categorized as:

4.1 Hard link switching

Hard link switching is the conventional way to perform the switching process. When strength of received signal goes
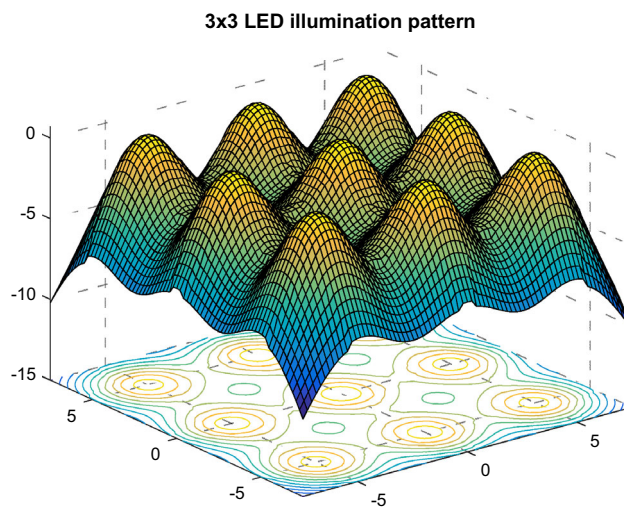

Fig. 2 3D Plot for Received Power Distribution

down the threshold level, switching process is initiated. First user scans the neighborhood to find the best transmitter and subsequently sends the request to coordinator to switch the link; which accepts the request and sends instructions to disconnect the current link. Once, this link is disconnected, next link association request is generated by the user device. Coordinator checks with the designated transmitter and if response of this transmitter is positive, the link association is performed. Main drawback of hard link switching is disconnection from the current transmitter before association from the next transmitter. This results in service disruption and QoS degradation. Further scanning period increases the switching delay in addition to the delay involved in switching process.

4.2 Soft link switching

Soft link switching ensures that the user device is disconnected from the current serving transmitter only when link between the new serving transmitter and user device is established. This procedure ensures that there is no interruption in service and QoS is maintained. But for this we must pay a price for complex and expensive hardware, and user device is needed to receive signals from two or more transmitters simultaneously thus waste resources, increases data traffic and may result in downlink interference. Also, there is possibility of service interruption or low QoS, as sometimes, user device may not receive signal due to interference. In some cases, selected transmitter may not have enough resources to accommodate the user device.

Presently, methods available for link switching are:

Each UD (User device) sends back acknowledgement to the coordinator whenever it receives data. if coordinator does not receive acknowledgement in predetermined time, it searches for the acknowledgement in the same time slot

736

Int. j. inf. tecnol. (April 2021) 13(2):733–740

in adjacent cells and if it found in other cell, control is transferred to corresponding cell [6].

Pre scanning & Received Signal Strength: In idle time UD checks signal from neighboring cells, makes a table; decides to switch link based on three thresholds [7].

We are hereby proposing a hard link switching algorithm, which does not require any complex circuitry and follows 802.15.7 standards for visible light communication. Proposed method is a novel approach because unlike conventional hard switching approach which allow the user to disconnect from a source when its signal strength is decreased to a minimum threshold. Then user searches for a new source to establish a new connection. Though our method, hard link switching approach pre scanning allows the coordinator to overlap the disconnection and new connection processes, bringing the link switching time ideally to zero.

Our Link switching process consists of following procedures:

5 Position estimation of mobile user

5.1 Recognition of the correct transmitter and Handover

First, we consider that in an indoor scenario where user devices are generally hand held devices and the speed of the owner of the device is not fast. We can also take the liberty that user generally moves approximately in a single direction with time and does not roam around arbitrarily. Second, we assume that with fixed interiors and light fixtures, the coordinator already has the information about the best suitable transmitter for any arbitrary position. With all these assumptions and information we propose a simple method of link switching which involves estimation of the future position of the user device and switching of transmitter links by the time user reaches that position. When user device receives or sends data in between two active periods there is an inactive or idle period. During this period UD scans the scenario and measures the strength of all the signals it receives. Then UD sends this measurement report to the coordinator. So, the proposed process starts with estimation of position of user.

5.1.1 Position estimation

In this paper, triangulation method has been used to determine the location of receiver since it provides better accuracy compared to global positioning system (GPS) in indoor environment for VLC transmission [22]. This technique helps to determine the location of receiver based on known positions of three transmitters. If T_1, T_2, T_3 are

three transmitters with known positions as shown in Fig. 3, then the position of receiver Rx (x, y) may be determined by solving the following equations where d_1, d_2, d_3 are derived based on the RSS from corresponding Txs.

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2 \tag{7}$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2 \tag{8}$$

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2 \tag{9}$$

Coordinator bounds the channel time in superframe structure. A superframe as shown in Fig. 4 is started and ended by the transmission of a beacon frame and can have an active portion as well as an inactive portion.

The Beacon Interval (BI) given by (10) defines the time between two consecutive beacon frames. BO is macBeaconOrder, SO is macSuperframeOrder and aBaseSuperframeDuration is a constant defined by the standard IEEE 802.15.7 [23] and is equal to 960 symbols, with a symbol time of 16 microseconds.

$$BI = aBaseSuperframeDuration \cdot 2^{BO} \tag{10}$$

Superframe duration (SD) defined by (11) gives the duration of the superframe.

$$SD = aBaseSuperframeDuration \cdot 2^{SO} \tag{11}$$

Thus, inactive period denoted by $T_{inactive}$ is.

$$T_{inactive} = BI - SD.$$

$$T_{inactive} = aBaseSuperframeDuration \cdot \left(2^{BO} - 2^{SO}\right) \tag{12}$$

During each inactive portion, user device measures the Received Signal Strength (RSS) of all the nearby transmitters and sends the measurement report repeatedly to the coordinator. Coordinator uses these RSS values to determine the current position of the user using triangulation method.
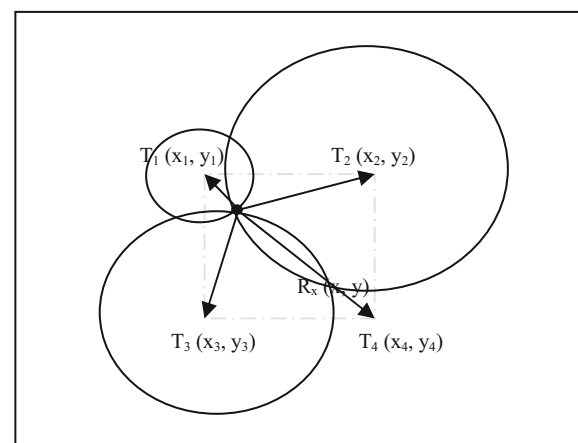

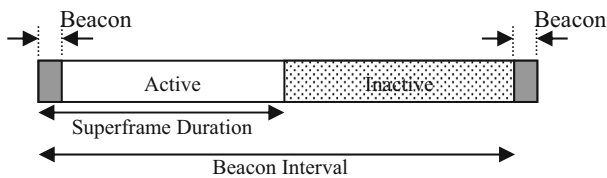**Fig. 3** Triangulation method for prediction of Rx point

Fig. 4 Superframe Structure[2]

Coordinator thus generates a path report for every UD and adds its new position after every dt_1 time interval (time between two inactive portions). Coordinator can predict the next position of the user using its previous path. If UD was at position $1(x_1, y_1)$ at time t = 0 and at position 2 at time t = dt_1, where dt_1 is the time interval between two inactive portions i.e. time interval between two measurement reports send by the user. Coordinator would calculate the next position of the UD at time t = $2dt_1$; time when user sends next measurement report.

$$x_e = x_2 + \frac{(x_2 - x_1)}{2} \tag{13}$$

$$y_e = y_2 + \frac{(y_2 - y_1)}{2} \tag{14}$$

Since user is moving with approximately same speed and direction; estimated position (x_e, y_e) will obviously be close enough to the actual position $(\times 3, y3)$ (Fig. 5).

5.1.2 Recognition of correct transmitter and handover

Coordinator uses this information to find the most suitable transmitter for this future position (Fig. 7). If this transmitter is different from the current serving transmitter; link switching process is initiated. Coordinator initiates both the disconnection process from the current transmitter and link association process with next transmitter simultaneously. This reduces the switching time and ensures minimum service disruption. By the time user reaches the next position, next transmitter starts the service. If dt_2 is the time taken by the link switching process and dt_1 is the time to reach next known position.

Then.

$$dt_1 \approx dt_2 \tag{15}$$

if dt_1 is nearly equal to dt_2 successful handover is done and user enjoys uninterrupted service, which is shown in Fig. 6. This call diagram explains the switching of network based on the estimation of current position of user, their
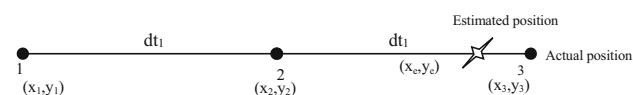

Fig. 5 Current position estimation

movement through synchronization the request via link switching and association.

6 Results and analysis

Table 1 shows the values of the parameters based on the scenario discussed in the proposed system model. These values were achieved by running the Position Prediction based link switching Algorithm. All the values have been calculated based on the velocity of the user at 0.5 m/s with the active number of 10 devices in the proposed system.

Key idea in this scheme is to rely on the accuracy of the prediction of the future position of the U.D. based on the direction and velocity of the user. This has been explained through the simulation, where, future positions are being predicted by the algorithm to enable the link switching mechanism. Figure 7 shows the simulation results of the position prediction of the user device.

Coordinator stores the intensity distribution value of each source in the room and predicts future position of the U.D as shown in Fig. 7 and Intensity values of Sources at User plane) to initiate the link switching process if required. This simplifies the mechanism as coordinator initiates the link switching and decides the best transmitter for user. Coordinator has the intensity distribution values of each of the source in the room. Coordinators use these two things (1. Future position of the U.D and 2. Intensity values of Sources at User plane) to initiate the link switching process if required. User need not decide or choose the best transmitter for itself, neither it had to initiate the link switching process. All is taken care by the coordinator.

Traditional link switching delay can be calculated as:

$$T_{trad} = t_{scan} + t_{decision} + t_{discon} + t_{linksw} + t_{linkasso} + t_{sync}; \tag{16}$$

where t_{scan} is the time to scan the neighboring transmitter after RSS reduced to a given threshold level, $t_{decision}$ is time taken by the user device to select the next transmitter, t_{discon}, t_{linksw}, $t_{linkasso}$ and t_{sync} are respectively time taken in present link disconnection process, new link establishment request, link association and synchronization process. Use of position prediction technique efficiently improves link switching delay time by eliminating the need of scanning and decision making time by user device. Also, the, link disconnection and new link establishment processes are performed simultaneously. This results in reduced link switching delay time. Link switching delay time in proposed scheme is given by (14).

$$T_{pred} = t_{discon/linksw} + t_{linkasso} + t_{sync}; \tag{17}$$

Simulation results are shown in Fig. 8. In this diagram, a comparison has been made between different link
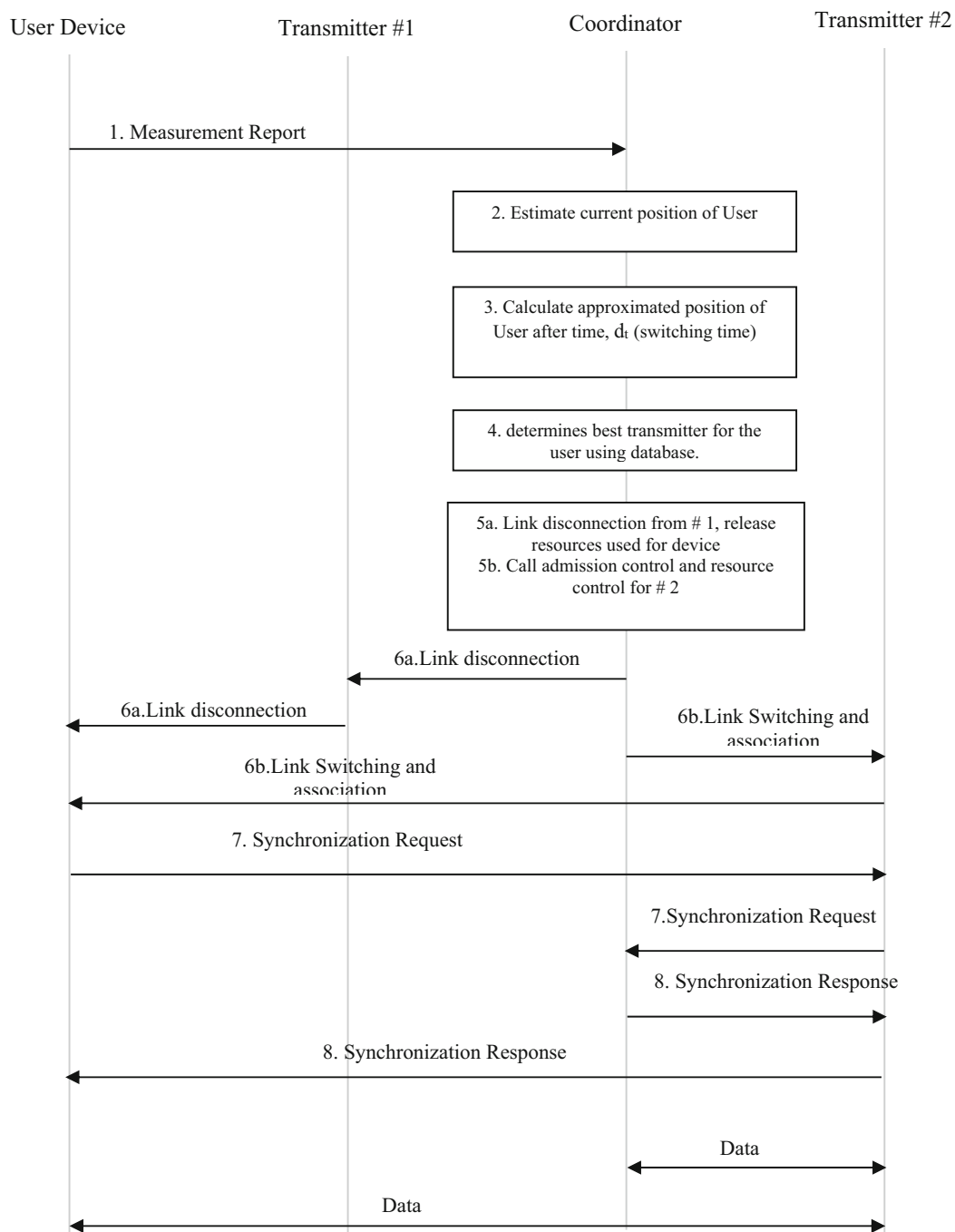
Fig. 6 Call flow diagram for proposed link switching algorithm

switching schemes like soft link switching, conventional hard link switching, pre-scanned received signal link switching with proposed Position Prediction based link switching scheme. This diagram clearly shows that the performance of the proposed link switching is much better than hard link switching and slightly lesser than soft link switching. However, on the basis of network complexity, it is much easier to implement than soft link switching.

Superiority of the proposed scheme over other existing position prediction method is that need of scanning of resources done by user in conventional methods is eliminated which reduce considerable amount of time; plus time required to decide for a new source to connect is also eliminated, also link disconnection and new connection request are not to be sent by the user. Coordinator himself issues the instructions and can almost overlap these two. These feature in our scheme reduces the link switching

Table 1 Simulation parameters

Parameter	Value
Room dimensions	12×12 m^2
Data rate	10 Mb/s
Photodetector Area	0.9 cm^2
Transmitter semi-angle at half power	15^0
Transmitted power	30 mW
BeaconOrder, BO	9
SuperframeOrder, SO	8
Average call duration	80 s
Number of time slots	160
Velocity of user devices	0.5 m/s
Number of user devices	10

Fig. 8 Simulation results of Link Switching Delay

time considerably and make this method most efficient of all the methods in the given scenario as shown by Table 2.

In the proposed algorithm, switching time remains almost constant as the link switching request is done by coordinator. In conventional methods, considerable amount of time is consumed in scanning the resources and making the decision to connect a new user. This time is reduced as.

7 Conclusion

The proposed Position Prediction based link switching scheme based on hard link-switching employing pre-scanning method works well with static indoor scenario. It can be implemented in normal offices/ workplaces where objects which can obstruct path of a light source are not moved on day to day basis. In such places, it is easy to use pre scanned information for link switching and any minor changes can be accommodated easily. The proposed scheme relies on the pre-scanned information of the indoor scenario stored in the coordinator's database, which can be refreshed at regular intervals, considering, indoor scenario is static with reference to the position of the objects and
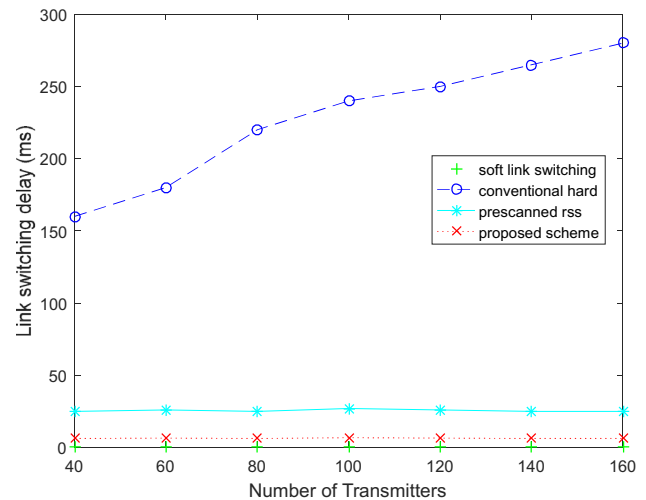
LEDs. Any changes, if occur, can be incorporated in the coordinator database. Since, link switching is done automatically so time delay due to link disconnection request and link switching is reduced, thus, reducing the overall switching time. Further, user need not initiate the link disconnection request and link switching request and thus switching time is reduced. Predicted position accuracy can be increased further by considering three or more previous positions; thus reducing link switching error. If link switching failure occurs three or more time at a position, coordinator database is updated for the same. In addition, this link switching method does not require any complex circuitry or any software changes in User Device. Present work sets path for some very promising future extensions. Our future work will involve implementation of this technique to more crowded places and manufacturing units where coverage areas of light sources are affected by movements of large objects and/or human beings randomly and frequently with relatively greater speed of movement. In future, this method can be employed for small vehicular movement inside large manufacturing units.
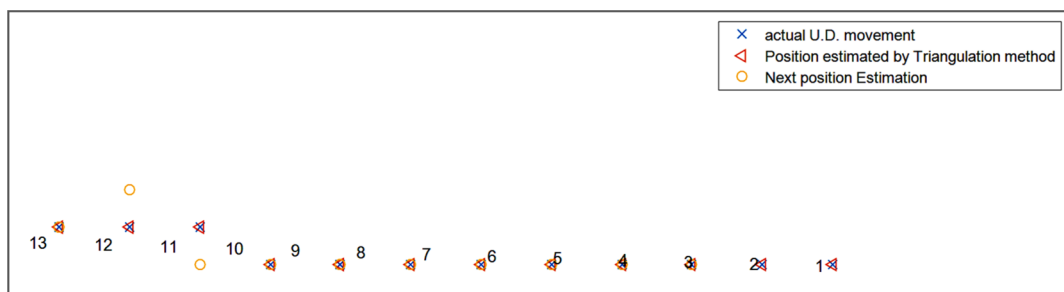

Fig. 7 Current position estimation, actual UD position future position prediction of MT

740

Int. j. inf. tecnol. (April 2021) 13(2):733–740

Table 2 Comparison of the various link switching methods

Link switching method	Basic mode of operation	Future_Position Est	Link Sw. Req	Switch criterion	Switching time
Prescanning and RSS prediction method [24]	Disconnection First and then new link is established	✘	On user device request	Threshold decided by U. D	Almost constant
Nth best node selection method [25]	Disconnection First and then new link is established	✘	On User Device request	Used When best node is not available	Increases when user number increases
Proposed Position Prediction based link switching scheme	Disconnection First and then new link is established	✔	Done by coordinator	Threshold decided by coordinator	Almost constant

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