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INTERFERENCE MINIMIZATION TECHNIQUES FOR LED-ID SYSTEM

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Abstract

LED-ID is a new and promising paradigm in the identification technology environment. It uses visible light as a medium for communication between LED-ID reader and tag. LED-ID system typically needs line of sight (LOS) to support narrow field of view (FOV) transceiver links to achieve high data rate but reduces the coverage, increases the disconnection rate of the link. Wide FOV enhances the coverage but increases the noise and interference. In LED-ID system interference is random in nature and hence its minimization is not easy task. When the number of readers or tags increases in any LED-ID system then interference minimization is the crucial task. Considering this issue we propose prioritized resource allocation based power control and wavelength hopping based interference minimization techniques for LED-ID system. Our simulation results show that proposed approaches perform better in both qualitative and quantitative measures over traditional methods.

Keywords: LED-ID system, interference, hopping, prioritized resource allocation, FOV

Introduction

LED-ID (Light Emitting Diode-Identification) system is one of the key technologies for identification, data transmission and illumination simultaneously. It is the new addition in the identification technology with the requirements of high data rate, high voice quality, multimedia features, gaming etc. LEDs are essentially used in LED-ID system because LED lights have been emerging as a new growth technology which is expected to replace existing illumination infrastructure for its long life expectancy, low cost, hasty response time high tolerance to humidity, low power consumption, and small size. Another important property that distinguishes it from traditional lights is that LEDs can be modulated in high speed, indicating it can not only be used to illuminate, but also play an important part in communication as a signal emitter. LED-ID technology based on the LED communication is ubiquitous information communication service that is used to supply variable information at museum, supermarket, and restaurant etc. Due to some tremendous features, LEDs can be used as tags in LED-ID system without losing their main functionality as illumination sources (Park *et al.*, 2010; Kim *et al.*, 2010). Compared with radio wave wireless communication, the use of visible light is harmless to humans, provides high security and license free (Komine and Nakagawa, 2004; O'Brien *et al.*, 2008). The visible light spectrum

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extends from 380 to 780 nm in wavelength. The standard is capable of delivering data rates sufficient to support audio and video multimedia services. For high data transmission, coverage area of tag and reader should be essentially narrow but it increases the number of tags to cover the required service area. In this case we have to consider mobility of the visible link, compatibility with LED-ID infrastructures. Moving reader acquires interference signals from other readers and tags when it is connected to its parent tag. LED-ID system commonly classified according to two criteria, namely, degree of directionality of the transmitter and receiver and whether the link relies upon the existence of a line-of-sight (LOS) path between them. Directed links employ narrow field-of view (FOV) transceivers that must be aimed in order to establish a communication link, while non-LOS links employ wide FOV transceivers that alleviate the need for such positioning. LOS links rely upon a direct path between the transmitter and receiver for communication, whereas non-LOS links usually rely upon reflection of the light from the ceiling or some other diffusely reflecting surface. In general, LOS links minimize path loss and maximize power efficiency, and they can achieve higher transmission rates (Dominic *et al.*, 2008). However, they are less robust and less convenient to use. While suffering from lower transmission rates, non-LOS links increase robustness and ease of use, allowing high user mobility and the links to operate even when there are barriers between the LED-ID tag and reader. But LED-ID wireless communication channel suffers from much impairment such as shadowing, and interference due to the multiple readers and tags. Number of reader in a cell is totally random in nature. Therefore interference is random rather than deterministic in LED-ID system and hence we can minimize it at a certain level except to avoid it. Consequently it is not easy task to minimize the interference at a certain level because several parameters such as power of tag and reader, movement of the reader, link switching; shadowing, unexpected obstacles etc. are involved. Considering these issues we propose a prioritized resource allocation based power control method and wavelength hopping pattern for minimizing the interference in a LED-ID system.

Materials and Methods

Light Emitting Diode Identification (LED-ID) is a technology that uses communication via light waves to exchange voice/video/data among one tag (or reader) to one or more identified readers (or tags).

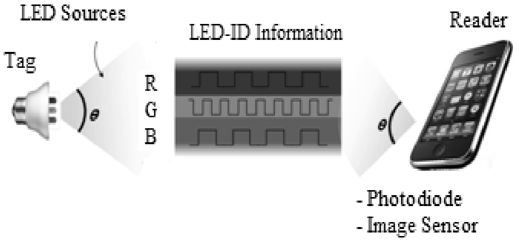

Fig. 1. LED-ID system.

Components of LED-ID: The main components of the LED-ID system are reader and tag. Each reader and tag of LED-ID has at least one LED and Rx module (PD/ image sensor etc.). The LED-ID tags are classified into active tag (ex. PD based) and semi-active tag (ex. image sensor based).

Service scenario of LED-ID: Museum, product expo, intelligent menu system (airplane, restaurant), advertisement, sign board, kiosk, indoor localization (LBS applications), inventory management system, car parking ,cleaning robot, guiding system for blind person, supermarket/department store, entertainment /movie/amusement park (Uddinet *et al*., 2011).

Characteristics of LED-ID: Low power consumption, harmless to human, green environment, high security, high speed read and write capability, no interference with RF, support QoS.

Wireless link model for LED-ID system: For a low cost LED-ID system, the most viable modulation is the intensity modulation (IM), in which the desired waveform is modulated onto the instantaneous power of the carrier. On the other hand, the most practical down-conversion technique is the direct detection (DD), in which a photo-detector produces current proportional to the received instantaneous power (Li *et al*., 2007; Sugiyama *et al.*, 2007; Elgala *et al*., 2010; Grubor *et al*., 2008). The average received optical power P_r generally can then be determined by

$$P_r = H_g(0)P_t \quad (1)$$

Where, P_t is transmitted optical power and $Hg(0) = \int_{-\infty}^{\infty} h(t)dt$ is the channel DC gain.

The received power P_r is determined by

$$P_r = [H_{gL}(0) + \xi H_{gNL}(0)]P_t \quad (2)$$

where dc gain $H_{gL}(0)$ and $H_{gNL}(0)$ for line of sight (LOS) and non-line of sight (NLOS) propagation respectively and

$$\xi\begin{cases}0 & LOS\\1 & LOS\ and\ NLOS\end{cases} \quad (3)$$

The channel dc gain $H_{gL}(0)$ can be determined by (Li *et al.*, 2007; Stojmenovic, 2002)

$$H_{gL}(0) = \begin{cases}\dfrac{(m+1)A}{2\pi D^2}\cos m(\varphi)T_s(\Psi)\ \cos(\Psi) & 0 \le \Psi \le \Psi_c\\ 0 & elsewhere\end{cases} \quad (4)$$

where m is the order of Lambertian emission, A is the photo-detector area, D is the distance between transmitter and receiver, φ is the angle of irradiance, ψ is the angle of incidence, $T_s(\psi)$ is the signal transmission coefficient of an optical filter, $g(\psi)$is the gain of an optical concentrator, and ψ_s is the receiver field-of-view (FOV).

The order of Lambertian emission m can be found from the equation, $m = -\frac{\ln 2}{\ln(\cos\alpha)}$ where α is the transmitter beam angle. The gain can be determined from the following expression (O'Brien *et al*., 2008).

$$g(\Psi) = \begin{cases} \frac{n2}{\sin 2\Psi c} & 0 \le \Psi \le \Psi c \\ 0 & else\,where \end{cases} \quad (5)$$

Where *n* denotes the internal refractive index of the optical concentrator.

The DC gain H_{aNL} taking the J reflection is (Uddin *et al*., 2011)

$$HgNL = \begin{cases} \frac{(m+1)A}{2\pi\prod_{j=1}^{J+1} D_j^2} dA\cos m(\varphi)T_s(\Psi)g(\Psi)\cos(\Psi)\times 0 \le \Psi \le \Psi c \end{cases}$$

$$H_{gNL} = \begin{cases} \frac{(m+1)A}{2\pi\prod_{j=1}^{J+1} D_j^2} dA\cos m(\varphi)T_s(\Psi)g(\Psi)\cos(\Psi)\times\prod_{j=1}\xi_j\cos(\alpha_j)\cos(\beta_j) & 0 \le \psi \le \Psi c \\ 0 & else\ where \end{cases} \quad (6)$$

Where D_j is the distance between transmitter and first reflective point, when j = 1, D_j is the distance between (j – 1)th reflective point and jth reflective point when j = 2, 3, ..., J and D_j is the distance between jth reflective point and receiver when j = j + 1. ξ_j is the jth reflectance factor. dA is reflective area of small region, α is the angle of irradiance to the receiver, $\beta$is the angle of incidence to the receiver.

Outage probability: In LED-ID system visible light is used as a transmission medium. Outage probability depend upon several parameters such as wavelength of transmission medium, field of view (FOV) of the reader and tag, number of readers (NoR) and tags (NoT) within the cell. As we mentioned before photo-detectors is used in each tag and reader. Photo sensitivity characteristics of photo-detectors depend on wavelength of the transmission medium. Due to this dependency on wavelength the performance is not same when receive signal using multi-color of channels in LED-ID system. One color of channel has less outage probability than other even though the radiometric received powers are equal on each color channel. Received signal depend on FOV of the reader and tag. Outage probability also depends upon the number of readers and tags in a cell and neighboring cell. Generally multiple tags is are used in a LED-ID system to cover the whole area. Reader in LED-ID system with multi tags, experiences interference from neighboring tags and readers. Wavelength hopping method reduces the outage probability considerably and improves the performance of the LED-ID system.

The outage probability of a LED-ID system is the probability that the instantaneous signal to interference and noise ratio (SINR) falls below a specified threshold β_{th} and denoted as (Uddin *et al.*, 2011)

$$
\begin{aligned}
P_{out} &= P_{rec}\,(SINR < \beta_{th}) \\
&= P_{rec}\left(\frac{\eta^2 R^2}{\sigma_I^2 + \sigma_N^2} < \beta_{th}\right) \\
&= P_{rec}\left(R2 < \frac{\sigma_I^2 + \sigma_N^2}{\eta^2}\beta_{th}\right) \qquad (7)
\end{aligned}
$$

where Y = f{$\lambda \in (\lambda_R, \lambda_G, \lambda_B)$, FOV, NoR, NoT} is a random variable of desired signal. In this case only three red (R), green (G) and blue (B) colors of channels are considered (Uddin *et al.*, 2011).

$P_{out}(\lambda_x$, FOV, NoR, NoT)

$$
= \int_0^{\frac{\sigma_I^2+\sigma_N^2}{\eta^2}\beta_{th}} \frac{1}{(\lambda x)} e - Y^2 (FOV) e - \left(\frac{2}{NoR + \in}\right) e - \left(\frac{\sqrt{2R}}{NoT + \in}\right) dY \qquad (8)
$$

Where R is the radius of the tag's coverage and η is the sensitivity of the photo detector .

Interference minimization techniques

Prioritized resource allocation based power control

LED-ID system is suitable for indoor application rather than outdoor. Here we consider an indoor LED-ID system's tags arrangement as shown in Fig. 2.

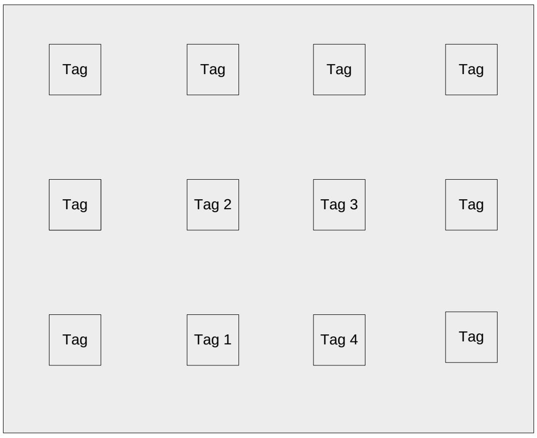

Fig. 2. Indoor LED-ID tag arrangements.

Although the real LED-ID tags arrangement in indoor application (Louvros *et al.*, 2014) is shown in Fig. 2 but for the purpose of analysis and simulation we consider four tags in a room in LED-ID system is shown in Fig. 3. Also assume that these four tags cover the whole area of the room where each tag has own coverage area. We can divide the whole area into several small areas covered by one, two three or four tags. For further analysis we can explain this system statistically considering some events. Possible random experiment consists of checking the system to see how many tags are currently connected to reader. Each tag is in one of two states: available (labeled 1) and not available (labeled 0). An outcome of the experiment (a point in the sample space) can be denoted by 4 bits (0's and 1's). A 1 in position i of the 4 bits outcome indicates that tag i is available and a 0 indicates that it is not. The sample space S has 2^4 = 16 sample points is shown in the Table 1.

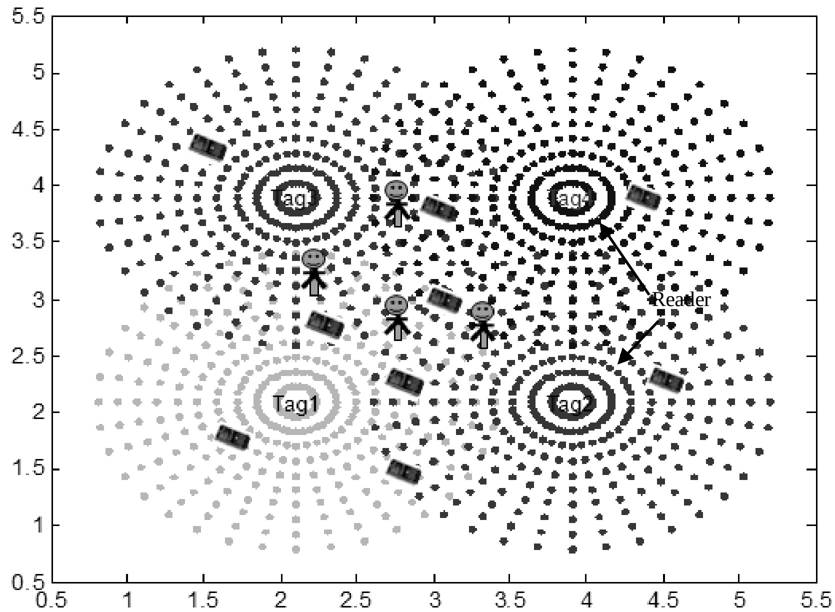

Fig. 3. Indoor tags arrangement of LED-ID system.

Table 1. Sample space

Sample points	$T_4T_3T_2T_1$	Sample points	$T_4T_3T_2T_1$
s_0	0000	s_8	1000
s_1	0001	s_9	1001
s_2	0010	s_{10}	1010
s_3	0011	s_{11}	1011
s_4	0100	s_{12}	1100
s_5	0101	s_{13}	1101
s_6	0110	s_{14}	1110
S_7	0111	s_{15}	1111

Figs. 4 and 5 shows the probability density function and cumulative distribution function respectively based on the circular cell configurations of the system is shown in Fig. 3. Here the probability density function shows probability of the coverage areas are overlapped by the tags x.

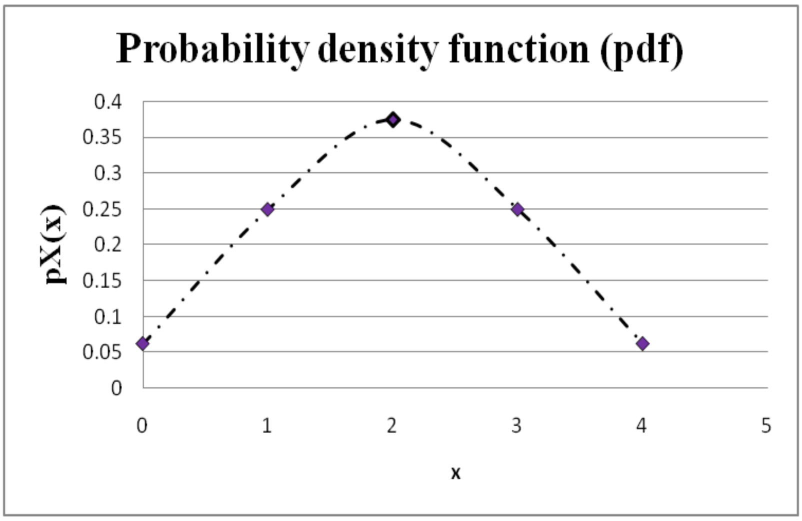

Fig. 4. Probability density functions (pdf).

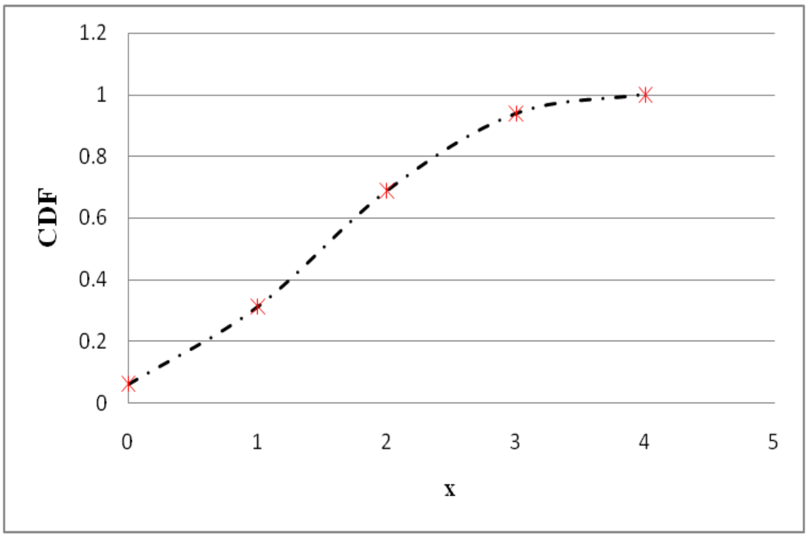

Fig. 5. Cumulative distribution functions (cdf).

In LED-ID system, as described before, each tag has the short range of coverage and hence need several tags to cover the whole area in a room. Communication link between tag and reader is not only line of sight (LOS) but also non line of sight (NLOS). NLOS means signal comes from tag to reader by passing different paths (Kumar *et al.*, 2008). Even though one reader connected to the one tag but it can receive signals from neighbor tags as well. Signals from neighbor tags are the interference for the reader when it is connected to the current tag. In this section, we explain the prioritized resource allocation based power control method for interference minimization for LED-ID system (Kahn and Barry, 1997). The total procedure is summarized as a block diagram in Fig. 6.

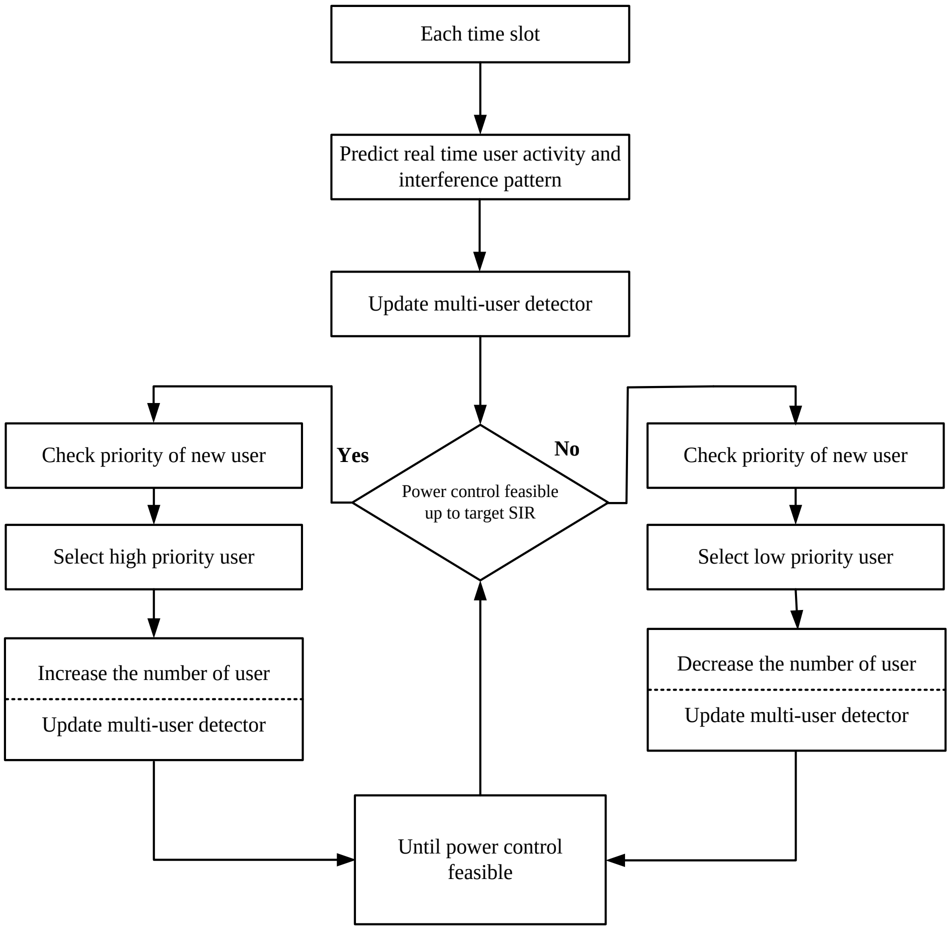

Fig. 6. Block diagram of prioritized resource allocation based power control method.

We consider in each time slot one or more reader tries to make link with tag. We can also consider the reader received signals from neighboring tags when it is connected to current tag. Proposed system can predict the real time user and interference pattern in the LED-ID system. Based on the interference and user activity, the power of tag and reader is controlled considering a target signal to interference ratio (SIR). Reader's received power is randomly varying with the interferences due to the neighboring tags and readers. Maintaining minimum SIR is essential for continuing connected link. We consider randomly varying received signal power is Gaussian distributed about its average value. Consider the target SIR, T_{SIR} for acceptable received power at a reader is W_0. The probability of the received signal power is equal or above the power at target SIR value is given by the following equation (Stojmenovic, 2002):

$$P[P_{rec} \geq P_{T_{SIR}})] = \frac{1}{\sqrt{2\pi\sigma}} \int_{P_{T_{SIR}}}^{\infty} \left(\frac{\{ P_{rce} - P_{avg}}{\sqrt{2\sigma}} \right)^2 d\,Pr\,ec \qquad (9)$$

where P_{rec} is a randomly varying received signal power, P_{avg} is the average received power, P_{TSIR} is the power at target SIR for acceptable received signal power of the reader and σ^2 is the variance. Within the target SIR new reader is added based on the priority of that reader and update the multi-reader detector. If the SIR condition is failed then low priority user lose his connection and update the multi user detector. Here we consider three class of reader such as low, medium and high priority reader. Blocking probability of each class of reader is defined as (Stojmenovic, 2002; Chowdhury *et al.*, 2014).

$$B_{HP} = \frac{\lambda_S^{C_1}\lambda_2^{C_2}\lambda_1^{C-C_2}}{\mu C!}P_0 \tag{10}$$

$$B_{MP} = \left[\sum_{k=C_2}^{C}\frac{\lambda_3^{C_1}\lambda_2^{k-C_1}}{\mu^k k!} + \frac{\lambda_3^{C_1}\lambda_2^{C_2-C_1}\lambda_1^{C-C_2}}{\mu C!}\right]P_0 \tag{11}$$

$$B_{LP} = \left[\sum_{k=C_2}^{C}\frac{\lambda_3^{k}}{\mu^k k!} + \sum_{k=C_2}^{C}\frac{\lambda_3^{C_1}\lambda_3^{C_1}\lambda_2^{k-C_1}}{\mu^k k!} + \frac{\lambda_3^{C_1}\lambda_2^{C_2-C_1}\lambda_1^{C-C_2}}{\mu C!}\right]P_0 \tag{12}$$

Where,

$$B_0 = \left[\sum_{k=0}^{C_2}\frac{\lambda_3^{k}}{\mu^k k!} + \sum_{k=C_2+1}^{C_2}\frac{\lambda_3^{C_1}\lambda_2^{k-C_1}}{\mu^k k!} + \sum_{k=C_2+1}^{C}\frac{\lambda_3^{C_1}\lambda_2^{C_2-C_1}\lambda_1^{K-C_2}}{\mu C!}\right]^{-1}$$

B_{HP}, B_{MP}, B_{LP} are the high, medium, low priority reader; C is the total number of possible link; C_1, C_2 and C_3 are maximum available link for low, medium and high priority reader; λ_{LP}, λ_{MP}, λ_{HP} are requested link mean rate for low, medium and high priority reader; $\lambda_3 = \lambda_{LP} + \lambda_{MP} + \lambda_{HP}$, $\lambda_2 = \lambda_{MP} + \lambda_{HP}$, $\lambda_1 = \lambda_{HP}$; μ is the link holding time mean rate. In this paper we consider both of above probability for getting high probability of link consistence (PLC) so that maximum number of reader can be accommodated in the system with tolerable interference.

Wavelength hopping

If interference is being experienced from adjacent tags then hopping can be used to mitigate it. When the LED-ID system uses the same time slot between the adjacent tag with multiple channel communication, and when multiple wavelength are supported by the physical layer (PHY), wavelength hopping can be used. In order to avoid interference and increase system capacity, pre-assigned hopping patterns should be adopted in LED-ID system.

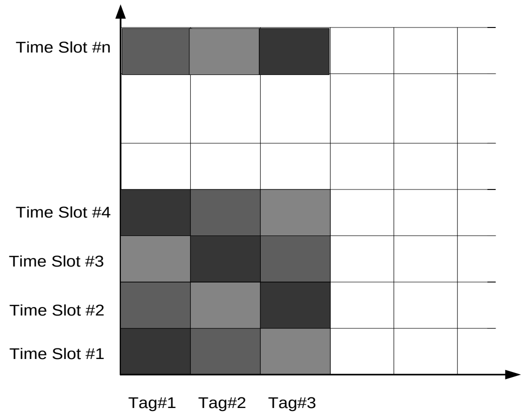

Fig. 7. Wavelength hopping for LED-ID system.

The hopping pattern should be assigned to the reader and then the reader should operate and hop based on the assigned hopping pattern. The hopping patterns structured so as not to change the visual perception of the light. For example, the patterns could hop between RGB in the proper time averaged portion so as to appear white (Elgala *et al.*, 2009). Hopping pattern is shown in Fig. 7 where it is assumed that red, green and blue are available at the tags. In LED-ID system hopping pattern application in the adjacent cell operates red (R) in first time slot, blue (B) in second time slot, green (G) in third time slot for tag 1 but tag 2 is operating at blue (B) in first time slot, green (G) in the second time slot and then red (R) in the time slot three. This mechanism can avoid interference between tags. Also the hopping pattern application does not limit one time slot. A hopping pattern across time slots is well. Also one hopping pattern or multiple hopping patterns can be assigned to one reader.

Results and Discussions

The Fig. 8 shows the probability of link consistence (PLC) versus the normalized interference level experience by the reader. Normalized interference level 0 means no interference i.e. very high SIR and 10 means the very high interference in the system.

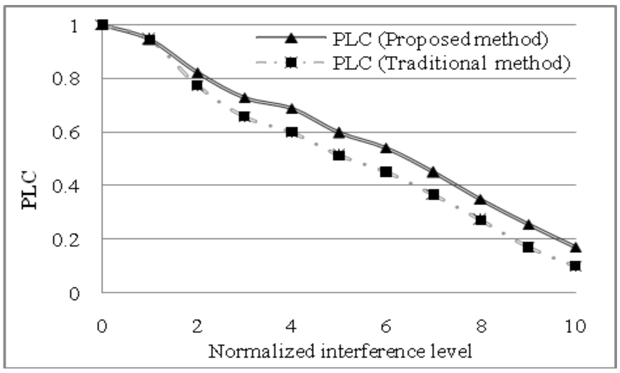

Fig. 8. Probability of link consistency of LED-ID system.

Prioritized resource allocation based power control method gives better link consistence than traditional method is shown in Fig. 8 considering the four tags in a room and fixed FOV of tags and readers. When the interference level is higher due to excessive readers or tags or both, then the PLC reduced drastically. Prioritized resource allocation based power control method gives the considerable improvement.

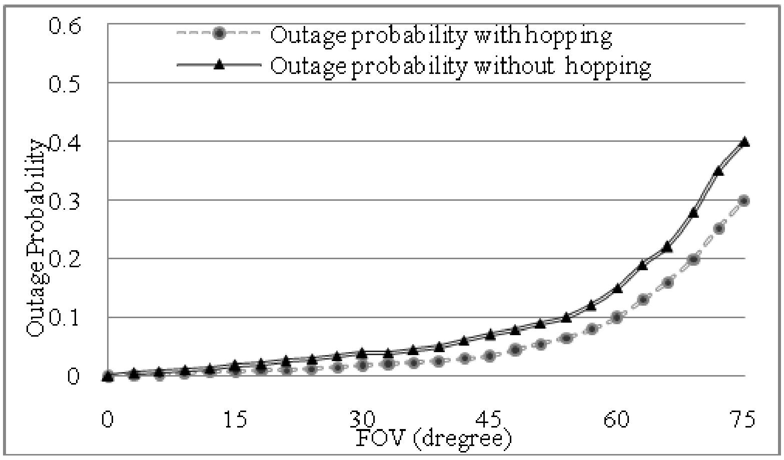

Fig. 9. Outage probability vs. FOV.

The Fig. 9 shows outage probability of link with and without hopping versus FOV. Outage probability increases when the FOV is increased because of receiving more interference due to wider FOV. Proposed hopping method gives the lower outage probability for the whole range of FOV than the traditional one is shown in Fig. 9.

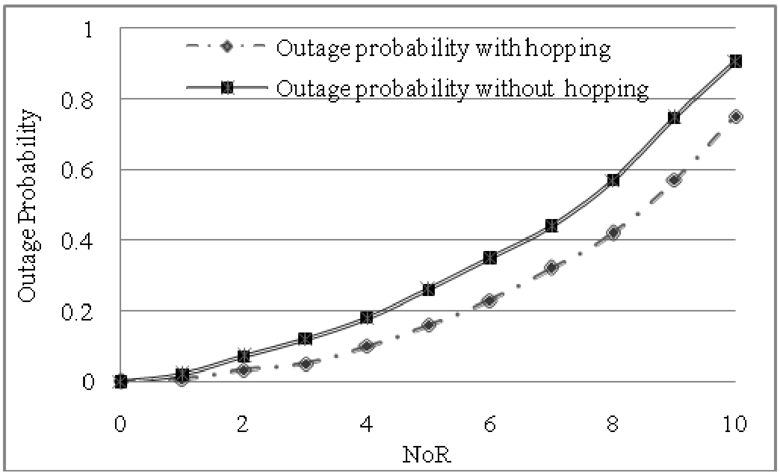

Fig. 10. Outage probability vs. number of readers.

The Fig. 10 shows the comparison between outage probability and the number of reader. If one reader connects to the tag then it experiences more interference when number of reader increases in the system and hence system gives more outage.

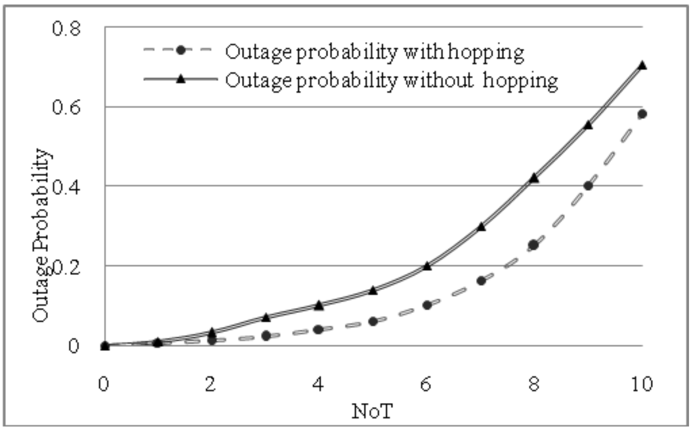

Fig. 11. Outage probability vs. number of tags.

The Fig. 11 shows the comparison between outage probability and the number of tags. Even though reader experiences more interference if the number of tags increases in a LED-ID system but more tags in the system make the coverage strong and reduce the outage probability.

Table 2. Results comparison

Figs.	Figure name	Measuring point	Improvement (%)
8	PLC vs. Normalized Interference level	Interference level 4	16.67
9	Outage probability vs. FOV	FOV 30 degree	19.7
10	Outage probability vs. number of readers	Number of reader 4	25.3
11	Outage probability vs. number of tags	Number of tag 4	20.3

Conclusion

In this paper we have shown the interference minimization techniques for LED-ID system. Reader in a LED-ID system experiences interference due to neighbor reader in the same cell or neighbor cell and tag of that cell. FOV is also the important issue in LED-ID system. Narrow FOV reduce the interference but reduce the coverage as well and consequently, increase the disconnection rate of the link. In this paper we propose prioritized resource allocation based power control method and wavelength hopping method for interference minimization. Simulations results show that proposed method reduce the interference of LED-ID and enhance the performance.

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