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Interference Minimization Using Cognitive Spectrum Decision for LED-ID Network

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ABSTRACT

LED-ID (Light Emitting Diode-Identification) network is envisioned to be the next generation indoor wireless communication medium by which simultaneously high speed data transmission, identification, and illumination are possible. In spite of being extremely promising, it suffers from much impairment. Signals having different propagation paths can suffer from delays, and phase shifts which will eventually result interference. The probability of interference is also increased when communication links are established between a tag and several readers. Therefore it is necessary to reduce the interference in LED-ID network to ensure quality of service. It is possible to avoid interference by knowing the information about readers prior to assign the available spectrum. In this paper, we have proposed dynamic spectrum decision using cognitive radio concept. The simulation results justify that the proposed scheme is better than the conventional scheme.

Key Words : LED-ID, cognitive radio, dynamic spectrum decision, interference.

I. Introduction

In recent years, we have witnessed a rapid growth of existing wireless service with the advent of numerous groundbreaking wireless applications. Using smart devices require constant internet connectivity and large amount of bandwidth for apposite working. Therefore, additional bandwidth demand is rapidly increasing. Considering the shortcomings of radio frequency (RF) spectrum, it is obvious that accommodating the increasing bandwidth demand for an increasing number of high data rate devices is quite impossible. As a result, spectrum scarcity has become a very important issue with proper interference management. As we seek solutions for spectrum inadequacy of contemporary RF wireless communication, optical wireless communication using light emitting diode (LED) can be an exact answer what researchers are looking for, especially in indoor environment. LED-ID system is such an optical wireless communication technology which has been subjected to tremendous amount of interest in the past few years. It is a green, and energy-efficient technology which facilitates the use of huge unregulated bandwidth lies within few hundreds of tetrahertz (THz) range, inevitably solves the increasing spectrum demand. A typical LED-ID system uses LED array, of which light intensity is modulated according to the data to be transmitted. It offers distinctive advantages compared with RF system[1]. It solves the bandwidth scarcity problem. Another perspective of using visible light spectrum for communication purpose is that there are no regulations regarding spectrum use concern.

In this paper, we concentrate on the cognitive spectrum decision approach to avoid interference among the readers. There is a possibility of existing many readers in the network and they may remain under same access point also called serving tag. On the other hand new readers may come and join the

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same tag and also moving readers might roam around the room and try to establish communication links with that tag. In that case, interference among the readers will become an officious issue and may cause signal outage for some readers especially for those, who are in the cell-edge area. Therefore the Quality of Service (QoS) will be reduced significantly. To avoid this unwanted problem, we introduce 'Dynamic Spectrum Decision', a cognitive concept in the LED-ID network. Cognitive radio[2,3] concept is widely used in heterogeneous RF network to provide high bandwidth communication, but for LED-ID communication this concept can be used for interference aware resource allocation and efficient bandwidth utilization. In our network scenario, tags send information about users to a coordinator. By using linear optimization algorithm, coordinator will make real time spectrum decision and allocate that spectrum to new reader such that minimum signal interference to noise ratio (SINR) is always maintained. Delay for spectrum allocation for a particular channel is also analyzed.

The rest of the paper is structured as follows. We present a synopsis over LED-ID system and indoor optical wireless models in Section II. In Section III, we present our cognitive scheme. Section IV presents numerical result, followed by conclusion in Section V.

Ⅱ. LED-ID Network Architecture overview

2.1. LED-ID Network Overview

In this section, we are going to give an overview on simple LED-ID network which has been subjected to vigorous study by many researcher in the past few years as an understudy of contemporary wireless communication system. In a LED-ID network, transmitters and receivers are termed as tags and readers respectively. Visible light is used as a transmission medium for communication among the tags and readers. Readers are the users who require information provided by the server via tags. LED-ID system works on two stages for data communication[4]. In the pre-identification stage reader is identified by

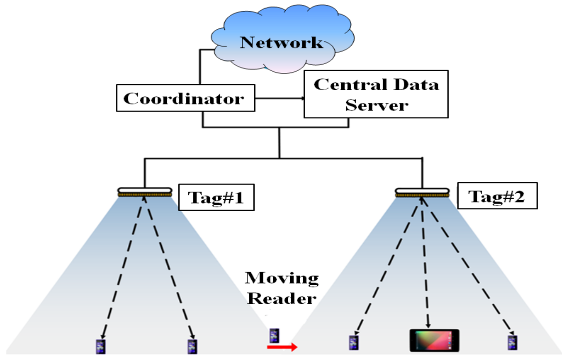

Fig. 1. Physical layer demonstration of a typical LED-ID system.

tag and then reader sends a request for desired information. In the post-identification stage, based on the reader's request, tag will allocate channel by the help of the coordinator. Fig. 1 shows a simple LED-ID system. In this Scenario, we introduce coordinator which works as a controller. For cognitive LED-ID system, controller is very important because it collects information from tags about readers and then combine all those information to make decisions on cell environment. Spectrum allocation for a particular channel for a new reader depends upon interference level in that cell. In general coordinator works as an intelligent node which controls the cell environment to limit interference and maintain QoS.

2.2. Interference in LED-ID Network

In LED-ID network visible light is used as a transmission medium. Even though visible light spectrum lies in THz range, we are unable to utilize this huge bandwidth due to the limitation of both transmitter and receiver frontend design. In order to provide efficient and ubiquitous coverage to serve multiple readers, reusing available bandwidth without interference is a key issue.

Now we are going to model interference in LED-ID network. The system will primarily suffer from thermal noise and shot noise. Light wave reflection and mutual position difference of each LED will create inter symbol interference (ISI) in the receiver side especially in high bit rate transmission and this effect can be analysed by the relation between normalized delay spread and bit rate as shown in fig. 2. Thus noise terms can be modeled as[5]

$$\eta = \eta_{Shot} + \eta_{thermal} + R_d P_{ISI}^2 \quad (1)$$

where R_d is the detector responsivity, η_{shot}, $\eta_{thermal}$ are the shot noise components and thermal noise component respectively, and P_{ISI} is the inter-symbol interference (ISI) component. Frequent movement of readers can over load cell capacity and cause signal outage in the process to some readers. On the contrary some cell may find few readers inside their coverage area to accommodate and find idle bandwidth in the system. For allocating multi reader under same tag bandwidth reuse policy can be used but that can lead to mutual interference between readers. Existing readers can also be affected by this policy. On the other hand the cell edge area will be more susceptible to co-channel interference (CCI). Thus multi user interference and CCI will severely affect the throughput performance as well as cause undesirable outage. CCI is caused by the new reader, when it tries to access the same channel already occupied by another reader and also edge area readers of the neighbour cell very often experience overlapping resources in the time-frequency slot. CCI reduces SINR, which, in turn, reduces throughput and

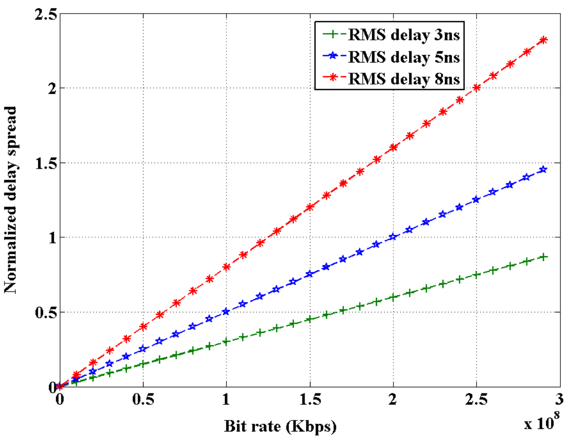

Fig. 2. Bitrate vs normalized delay spread. High bitrate transmission increases normalized delay spread which increases ISI effect.

can even lead to undesirable interruption in continuity of communication when the SINR drops below the level necessary. Consider, in a LED-ID network reader j is communicating with serving tag i by a channel k. Each reader is assigned with different channel, depends on available resource and required bandwidth demand. Another reader a comes to the network and joins the same tag i. CCI is caused by the reader a on reader j is denoted as I_j, $I_j = R_d H_{i,\alpha} P_i$. $H_{i,\alpha}$ is the optical channel gain for reader a in channel k. Channel gain is different for every reader even though they may occupy the same channel differentiated by time frequency slot arrangement. If the reader j stays in edge-area of the tag i and another reader β of neighbouring tag i', then CCI on reader j is $I_j' = R_d H_{i',\beta} P_{i'}$. If m is the number of readers from neighbour tags causing CCI on reader j, overall CCI can be written as

$$I_{CCI} = \sum_{\alpha=1}^{l} R_d H_{i,\alpha} P_i + \sum_{i'=1}^{q} \sum_{\beta=1}^{m} R_d H_{i',\beta} P_{i'} \quad (2)$$

We assume coordinator controlled LED-ID network which is capable of collecting a priori information about channel and reader, therefore update channel parameters according to that information. Thus it can decide whether to allow new user or not in the actual time of occurrence. We also assume that tags will cooperate with coordinator and also exchange information of their serving regions in order to make the coordinator cognizable. Therefore depending upon the SINR value, coordinator can control CCI, and to limit ISI, it can make subtle adjustment in transmission bit rate by itself, to maintain reasonable QoS. SINR for channel k can be calculated as follows

$$\gamma_k = \frac{R_d H_{i,j} P_i}{I_{CCI} + \eta} \quad (3)$$

where P_i is the transmitted power by tag i in channel k. Readers should receive signal with a minimum SINR value to ensure quality communication such that bit error rate (BER) will remain in allowable limit. To satisfy the SINR target, channel capacity and bandwidth are needed to be estimated each time when a new reader comes to access the channel for communication. To avoid interference due to CCI, a smart coordinator is needed which can take decision on a priori SINR estimation by observing interference under each serving tag. Therefore channel can be assigned only if following criteria is satisfied

$$\gamma_k \geq \lambda_{\min} \quad (4)$$

where λ_{min} is the threshold value of SINR. To estimate SINR target for a new reader, tags are required to cooperate and information of interference observation are needed to be sent to coordinator. For this purpose we assume a dedicated control channel among the tags and coordinator.

Ⅲ. Cognitive LED-ID network

In this section, we review the cognitive concept in LED-ID network. In RF system, Cognitive radio aims to detect either the presence of primary user or the spectrum occupancy by primary user. On the other hand, in the case of cognitive LED-ID network we cannot exactly use the primary user (PU), secondary user (SU) terminology because we can not identify reader's state on the basis of licensed or unlicensed spectrum occupation since the visible spectrum is unlicensed. Traffic condition in a cell is always changing because readers move from one cell to another frequently. Therefore it is necessary for LED-ID network to have a self organizing network architecture in order to avoid collision and interference. Conventional approach uses cluster based frequency planning concept and static reuse partitioning[6]. The shortcoming of such approach is inefficient bandwidth utilization. There is a possibility of idle bandwidth in the system even though allocation of those bandwidth will not cause considerable amount of CCI. Moreover using such approach may lead to wastage of important resources since traffic load varies widely among the cells in a network.

3.1. Dynamic Spectrum Decision Framework

We propose dynamic spectrum decision for new readers arriving in a cell under a new serving tag. In our model, coordinator optimizes interference level and makes spectrum decision upon reader's appearance and interference level. We assume our system can be aware about movement of the readers by exchanging information among tags and coordinators. Every readers can have different spectrum band depending on the existing resource level such as available bandwidth, and data rate loss. But interference level is the most important parameter to consider making spectrum decision. When a tag detects reader's request, it passes that information to coordinator along with active and idle reader information. In LED-ID network, spectrum condition is ever so changing. Therefore spectrum decision requires dynamic approach. For the case of idle readers, spectrum situation is a bit tricky. Because of idle readers some spectrums remain unused either for a brief interval or for a long time. It is possible to reuse these spectrums for new reader for providing it the much needed bandwidth but when idle one becomes active, recently allocated reader should release that spectrum in order to limit CCI. In this sense dynamic approach will provide greater flexibility and reliability. After receiving request, coordinator checks the current spectrum condition and reconfigures the resources for that tag. It will only accept new users if and only if interference level is satisfied.

For making spectrum decision the following steps are carried out at the coordinator.

(1) Make an a priori SINR estimation based on interference level.

(2) Check spectrum occupancy of the existing readers.

(3) Check bandwidth demand of the new reader; $B_{required} \leq B_{available}$.

(4) Make an a posteriori estimation of SINR (γ_{post}) level.

(5) If $\gamma_{post} \geq \lambda_{min}$, accept new reader.

From SINR point of view, we consider CCI is dominant so that for decision making case we neglect the effect of ISI and other noises. Let, y_k be the decision variable. It can be defined on the basis of the channel occupancy such that

$$y_k = \begin{cases} 1, & \text{if } channel\, k\, is\, occupied \\ 0, & elsewhere \end{cases} \quad (5)$$

The spectrum decision is taken by coordinator using linear optimization algorithm.

$$\text{Maximize: } \sum_{k=1}^{N} [B_{opt}(j) \log_2 (1 + \lambda_{\min})] y_k \quad (6)$$

$$\text{Subjected to: } \sum_{k=1}^{N} y_k \le n \quad (7)$$

$$B_{opt}(j) \le B_{available} \quad (8)$$

where N is the total number of available spectrum bands, n is the number of communication links with tag. In the optimization, the spectrum band selection depends on number of communication links. $B_{available}$ is the available bandwidth of the serving tag. $B_{opt}(j)$ is the optimized bandwidth for reader j. Coordinator optimizes bandwidth so that allocation of that spectrum portion should not cause detrimental CCI towards other readers both in the serving tag and the neighbour tags. Therefore the proposed approach ensure efficient bandwidth utilization. The optimized bandwidth can be found by

$$B_{opt}(j) = B_{total} - B_{occupied} + B_{reused} \quad (9)$$

where B_{total}, $B_{occupied}$ are the total bandwidth, and occupied bandwidth of the existing reader of the serving tag respectively, and B_{reused} is reused bandwidth. The amount of bandwidth which is going to be reused is being decided by coordinator after it makes an a posteriori SINR estimation.

3.2. Spectrum Allocation delay Analysis Using Confidence Interval(CI)

In this section, delay for spectrum allocation for a particular channel is analyzed using confidence interval (CI). Delay may occur in allocating spectrum if any tag is unable to send necessary information within desired time interval. Therefore it will affect the reliability of the proposed approach. We can estimate this allocation delay by using CI. For CI[7] estimation, let the set of random variables $x_1, x_2, \ldots\ldots, x_t$ is called a sample of size t from the population T and the population is normally distributed. The sample mean is $\bar{x}$ and sample standard deviation is σ. If the standard error is E then the minimum number of sample is

$$t = \left(\frac{z_{\delta/2} \cdot \sigma}{E} \right) \quad (10)$$

If the variance of the population is unknown and the sample size is small, the (1-δ)100 percent confidence interval for the population mean μ is

$$\left(\bar{x} - z_{\delta/2} \frac{s}{\sqrt{t}}, \bar{x} + z_{\delta/2} \frac{s}{\sqrt{t}}\right) \quad (11)$$

When X is normally distributed then by using Chi-square distribution of $t-1$ degree of freedom for (1-δ)100 percent confidence interval the population variance σ^2 is

$$\frac{(t-1)S^2}{X^2_{t-1;\delta/2}} < \sigma^2 < \frac{(t-1)S^2}{X^2_{t-1;1-\delta/2}} \quad (12)$$

X^2_{t-1} has Chi-square distribution with $t-1$ degree of freedom.

Table 1. Minimum number of samples for spectrum allocation delay

Error (%)	Minimum number of samples	
	95% CI	99% CI
1	43,794	79,430
2	10,949	19,858
3	4,866	8,826
4	2,737	4,964
5	1,751	3,177
6	1,217	2,206
7	894	1,621

For the analysis we have the sample size 401. Thus for *(t-1)* i.e. 400 degree of freedom, we calculate σ^2 by using Chi-square distribution table. The number of samples, which are needed to get more correct results from the sampled data are listed in Table 1. Therefore, it is possible to choose sample size for estimating and reducing delay depending on the network environment and QoS requirement.

Table 2. Simulation parameters

Parameter	Value
Transmitted optical power	1W
System bandwidth	20 MHz
SINR threshold	9.3 dB
Distance between reader and tag	3m
Physical area of the PD	150 mm^2
Transmission coefficient of filter	1.0
Concentrator FOV	60 (degree)
Semi-angle at half power	15 (degree)
Refractive index	1.5
Number of tags	8
Number of readers	20

Ⅳ. Performance Analysis

According to our proposed model, coordinator will decide on those spectrum bands for which SINR is above threshold value. As we mentioned earlier that each time a new reader wish to join under new tag, coordinator will estimate SINR threshold. The values of the parameters are listed in table 2, which we used in our simulations.

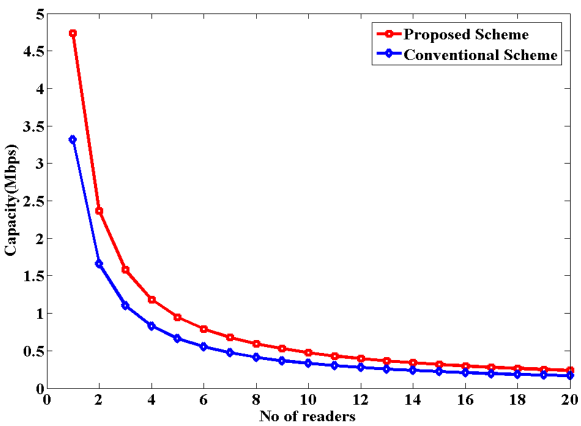

Fig. 3. Comparison of capacity enhancement.

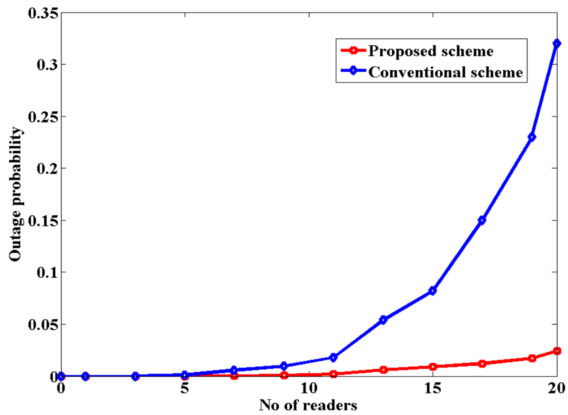

Fig. 4. Outage probability analysis.

Fig. 3 shows the effectiveness of dynamic spectrum decision. It shows that proposed scheme enhances the capacity where conventional scheme cannot guarantee high capacity for same number of readers. Fig. 4 shows outage probability analysis. Simulation result shows that proposed approach gives less outage to readers comparing with conventional system which does not use dynamic interference coordination. Proposed approach gives better interference coordination especially for edge area readers thus resulting low outage.

Ⅴ. Conclusions

LED-ID network is going to be the new paradigm in a quest for green and high speed communication. However interference coordination remains a challenging issue in order to fulfill that quest. Therefore a dynamic spectrum decision framework has been proposed for LED-ID network in order to minimize interference. We aim to reduce interference and keep the SINR into allowable level. The proposed scheme can decide on selecting spectrum dynamically considering reader occupancy and CCI level in the same time intend to accommodate maximum possible numbers of readers and by choosing sample size correctly and carefully, system reliability can be improved. Simulation result shows significant improvement in the system performance.

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