Wireless Optical Trasnsmissions with white colored LED for Wireless Home Links

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ABSTRACT — In this paper, we propose the wireless optical communication system with white colored LEDs for wireless home link (WHL). The white colored LEDs have a high power output and are regarded as lamps for the next generation. In the proposed system, this device is used for wireless home link. The proposed system is suitable for private networks such as consumer communication networks. From numerical and simulation results, it is confirmed that the proposed system is available and the problems to be solved are made clear.

1 INTRODUCTION

In the 21st century, high speed data transport will play an important roll in our life. We will be able to have many kinds of informations, which are so called multimedia informations, in any place at any time. Of course, high speed data containing these informations will come not only to offices but also to our homes. Therefore the concept of wireless home link (WHL) has been proposed and drawing considerable attention [1]. The electrical appliances will be wireless-linked with each other in the 21st century. Using WHL, we, including these appliances, will access the worldwide Internet everywhere in our home. An example of WHL is shown in Fig. 1.

For WHL, wireless optical communications can be considered as a candidate. It is suitable for WHL which needs high speed wireless links because it has the following features:

- Wide bandwidth is available for an optical carrier and is suitable for high speed transmission.
- The optical devices are small and low in cost. Thus they can simplify the structure of transmitters and receivers.
- The optical wireless networks need no license.

Especially, the wireless optical links are suitable for non-public networks, or consumer communication networks, such as WHL which is the topic here because they do not request any licenses. Moreover, lightwaves are obstructed only by physical obstacles, and it is easy to prevent the interference from adjacent rooms. Therefore the transmission by lightwaves is more suitable for indoor wireless networks than the one by radio waves.

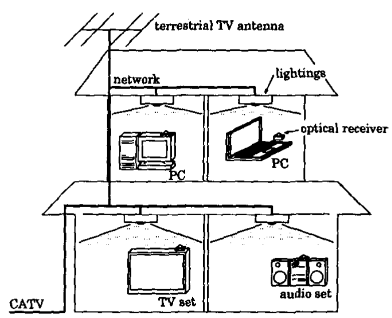

Fig. 1 An example of wireless home link using the lighting equipment.

On the other hand, white colored LEDs (light emitting diodes) are also drawing attention [2]. They are considered as lamps for the next generation. However, it has been impossible to obtain white colored LEDs until recently due to the lack of highly efficient blue and green LEDs. Now, InGaN based highly efficient blue and green LEDs have become commercially available. Using these LEDs, it is possible to fabricate white colored LEDs by mixing lights from LEDs in the three primary colors (red, green and blue). The white colored LEDs have a bright output, a high power efficiency and a long life. They are to play a principal part instead of incandescent or fluorescent lights in our home [3].

In this paper, we propose the wireless optical communication systems with white colored LEDs for wireless home link. In the proposed system, lighting equipment is able to have a capacity for wireless optical communications. The proposed system has the fol-

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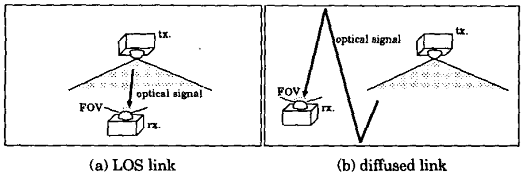

Fig. 2 Two kinds of optical link configurations.

lowing advantages:

- High power lighting equipment makes it possible to communicate in the whole room.
- Lighting equipment with white colored LEDs is easy to install and looks nice.

This paper is organized as follows. In section 2, the indoor optical channel model is shown. The received optical power is discussed in section 3 and section 4 presents the computer simulation results in the assumed channel. And, we give our conclusions in section 5.

2 INDOOR OPTICAL CHANNEL

In this paper, we mainly evaluate the performance in down link. Thus the down data stream of the proposed system is described in this section.

Informations arrived at home flow into the home network and are taken out from the access points in each room. In the concept of WHL, radio wave bands in 5, 25, 40, and 60[GHz] are used as information carriers [1], and radio wave antennas are used as access points. In this paper, however, we propose using lightwave transmission and optical lamps are adopted as access points. The optical lamps are composed of white colored LEDs. The white colored LEDs in the access points do not only illuminate our room but also modulate electric signals into lightwave signals and those lightwave signals are emitted into the air.

There are several kinds of link structures [4]. The major discrimination is how to propagate an optical signals by an LOS (line-of-sight) link or a diffuse (non-LOS) link. These links are shown in Fig. 2. In the LOS link, a receiver can get high power lightwave, however it is considered to be inappropriate for the proposed system because the main role of lamps is to illuminate the whole room. Therefore multipath needs to be considered even though it is not preferable. And the received signal $r(t)$ is given by:

$$r(t) = s(t) \otimes F(\tau) + n(t), \tag{1}$$

where $s(t)$ is the transmitted signal, $F(\tau)$ is the multipath channel and $n(t)$ is the additive white gaussian noise (AWGN). In fixed transmitter and receiver locations, multipath dispersion is completely characterized by an impulse response $F(\tau)$. The impulse

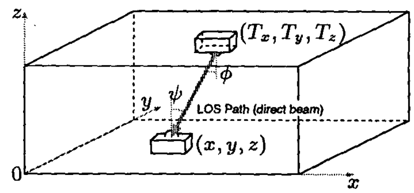

Fig. 3 Room configuration for calculating the received optical power.

response can be used to analyze or simulate the effects of multipath dispersion in indoor optical channels. Gfeller and Bapst modeled the channel impulse response as follows [5]:

$$F(\tau) = \begin{cases} \dfrac{2\tau_0^2}{\tau^3 \sin^2(\mathrm{FOV})}, & \tau_0 \le \tau \le \dfrac{\tau_0}{\cos(\mathrm{FOV})}, \\ 0, & \text{elsewhere.} \end{cases} \tag{2}$$

where $\tau_0 = L/c$ is the minimum delay and FOV is the field of view of the receiver. In this paper, we adopt this multipath channel model in the simulations. In this model, the Lambertian reflection is assumed. This link is a diffuse link. Optical pulses from a transmitter are reflected and received at an optical receiver. In this transmission, the optical pulses suffer from intersymbol interference (ISI).

3 RECEIVED OPTICAL POWER

As described in section 2, the indoor wireless optical channel is expressed by the Gfeller and Bapst model. Multipath delay is calculated from the power of a direct beam with Eqs. (1) and (2). Therefore the received optical power of a direct beam is calculated and described in this section.

The lighting equipment composed by white colored LEDs, whose emission pattern is assumed to be Lambertian, will be placed on a ceiling. In Lambertian emission, the radiant intensity P_{tr} depends on the angle of irradiance ϕ, and is described as follows:

$$P_{tr}(\phi) = \frac{m+1}{2\pi} P_s \cos^m(\phi), \tag{3}$$

Table 1 Parameters in the calculation.

angle of incidence	$\psi = 0$ [deg.]
angle of irradiance	$\phi = 0$ [deg.]
gain of lens	$g = 2.41$
gain of optical filter	$T_s = 1.0$
physical area of PD	$A = 0.1$ [cm^2]
transmitted power	$P = 20.0$[dBm]
transmitter position 1	$(1.5, 7.5, 5.0)$
transmitter position 2	$(4.5, 7.5, 5.0)$
transmitter position 3	$(7.5, 7.5, 5.0)$
transmitter position 4	$(10.5, 7.5, 5.0)$
transmitter position 5	$(13.5, 7.5, 5.0)$

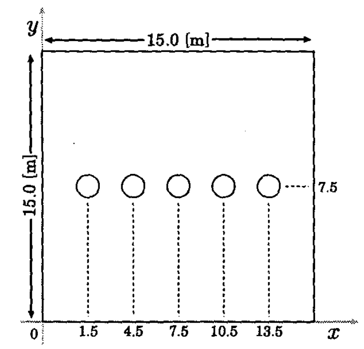

Fig. 4 The position of lighting equipment composed of white colored LEDs.

where P_s is the total power transmitted by an LED and m denotes the directivity of an emission pattern, which is derived from a semiangle at half power $\Phi_{1/2}$ as follows:

$$m = -\frac{\ln 2}{\ln \cos \Phi_{1/2}}. \qquad (4)$$

The larger m is, the sharper the beam of an LED becomes.

The channel DC gain is discussed in [4], and given by:

$$F(0) = \frac{(m+1)A}{2\pi d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi), \quad 0 \le \psi \le \mathrm{FOV}, \qquad (5)$$

where A is a physical area of a detector in a pin-PD (photo diode), d is a distance between a transmitter and a receiver, ψ is an angle of incidence, ϕ is an angle of irradiance, $T_s(\psi)$ is a gain of an optical filter, and $g(\psi)$ is a gain of an optical concentrator. FOV denotes width of a field of vision at a receiver. The optical concentrator $g(\psi)$ can be given as [6]:

$$g(\psi) = \begin{cases} \dfrac{n^2}{\sin^2(\mathrm{FOV})}, & 0 \le \psi \le \mathrm{FOV}, \\ 0, & \psi > \mathrm{FOV}, \end{cases} \qquad (6)$$

where n denotes a refractive index.

We calculate the received optical power of a direct beam. The room size is (15.0[m] × 15.0[m] × 5.0[m]). The channel parameter is shown in Table 1 and the position of lighting equipment and a receiver is shown in Fig. 3. The angle of incidence and of irradiance is both 0[deg.]. It means that the direction of lighting equipment and a receiver is perpendicular to the ceiling and the floor, respectively. Five pieces of lighting apparatus are installed on the ceiling and the arrangement of these is shown in Fig. 4 and their positions are shown in Table 1.

Figs. 5 and 6 show the received optical power of a direct beam: in Fig. 5, the power versus a variety of half power angles at a transmitter is shown, and the power versus a variety of FOVs of a receiver is shown in Fig. 6. Fig. 5 shows the effect of directivity at a transmitter. In this figure, x, y-axes present the position of a receiver and the vertical axis presents the received optical power at a receiver. From this figure, we can find that the half power angle of a transmitter affects the received power in each position. From Fig. 6, it is found that the narrower the FOV is, the larger the received power is, however the coverage area is restricted. When the FOV at a receiver is wide, the average received power is low all over the room.

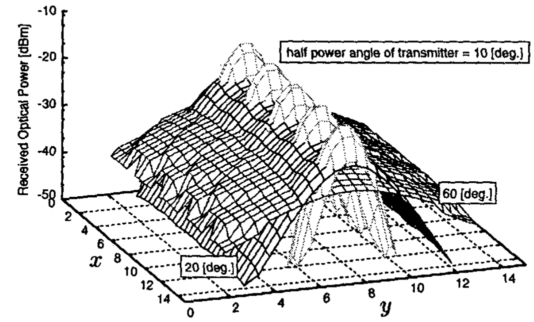

Fig. 5 Received optical power of a direct beam, when the FOV of a receiver is fixed to 55[deg.] and half power angle is varied.

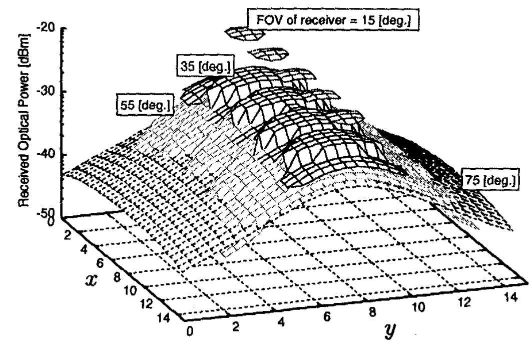

Fig. 6 Received optical power of a direct beam, when the half power angle of a transmitter is fixed to 60[deg.] and the FOV of a receiver is varied.

From these figures, it can be found that the FOV at a receiver is an important factor for the configuration of the proposed system.

The FOV at a receiver satisfies the following equation so as to detect a lightwave from lighting equipment everywhere in the room:

$$\mathrm{FOV} \ge \tan^{-1}\left\{\frac{\max(X,Y)/2}{H}\right\}, \qquad (7)$$

where X, Y is the room size, H is the room height and $\max(X,Y)$ indicates that a larger value is taken from X and Y. Under the configuration shown in Table 1, the FOV at a receiver is needed to be larger than 56.3[deg.]. But a larger value in the FOV lowers

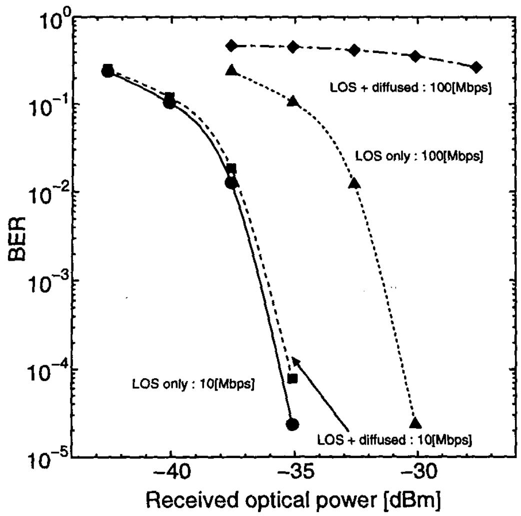

Fig. 7 BER vs. received optical power: FOV = 56.3[deg.] from Table 1.

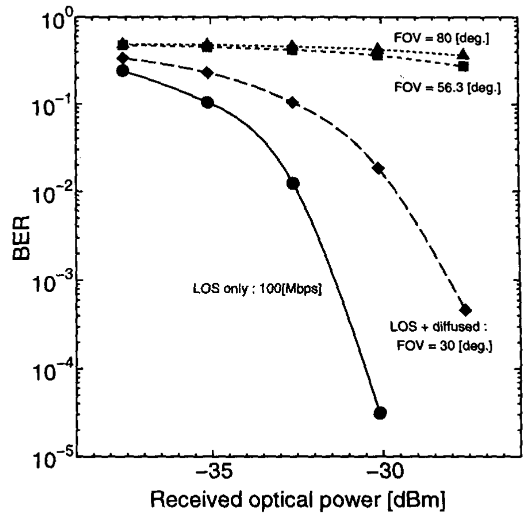

Fig. 8 BER vs. received optical power: under various FOV, the data rate is 100[Mbps].

the received optical power as a whole. Therefore, it is considered to be optimal when the equality is formulated in Eq. (7) in terms of the received optical power at a receiver.

4 SIMULATION RESULTS

In this paper, the computer simulations are performed. Table 2 shows the general simulation parameters.

The channel is assumed to be an indoor optical channel, whose model given by Gfeller and Bapst was presented in section 2. Intensity Modulation and Direct Detection (IM-DD) are used as the optical modulation scheme. In this paper, we do not consider the effects of difference in optical wavelength of the carriers for error performance because this system adopts IM-DD. Subcarriered-BPSK [7] is applied as a modulation scheme. Noise in optical transmission is assumed to be AWGN. The distance between a receiver and a transmitter is 5.0[m], and the FOV of an optical receiver is $\pi/3.19$[rad.]. The power of ambient light noise is 0[dBm], and the O/E (optical to electrical) conversion efficiency at a receiver is 0.53[A/W]. In this simulation, data bits from plural lighting fixtures are assumed to be synchronized at a receiver, and the delay is caused by the only ISI.

Table 2 General simulation parameter.

Channel model	Gfeller and Bapst model
Modulation	Subcarriered-BPSK
Height of the room	5.0[m]
FOV of the receiver	$\pi/3.19$ ($\doteqdot$ 56.3[deg.])
Ambient light noise	0.0[dBm]
O/E conv. efficiency	0.53[A/W]

Fig. 7 shows the BER performance versus the received optical power. In this figure, two cases by the only LOS link and by the LOS with a diffuse link are depicted. It can be seen that the effect of ISI becomes larger in the case of larger data rate. In the environment with only LOS path, the bandwidth of AWGN determines the performance, while the effect of ISI degrades the performance more when a multipath dispersion is considered. When the data rate is 100[Mbps], we cannot communicate in most part of the room.

Fig. 8 shows the BER performance under various FOV configurations. In this simulation, the data rate is fixed to 100[Mbps]. The FOV at a receiver affects the quantity of multipath components. The wider a FOV is, the larger amount of multipath a receiver detects. The performance is degraded in such case. In section 3, we have discussed a FOV in terms of received optical power. From this figure, we can find that a wider FOV degrades the performance at a receiver in terms of multipath effect. Therefore it is important to choose a proper FOV at a receiver.

In our study, a multiple subcarrier transmission system is also considered and Fig. 9 shows the effect of multiple subcarrier transmission. In this simulation, the FOV of a receiver is 55[deg.] and the other parameters are the same as before. From this figure, we can find that the multiple subcarrier modulation has a better performance than the single carrier modulation case. However it has the "floor" in the BER performance. This is generated by the property of a diffuse lightwave channel which cuts a high frequency. Fig. 10 shows spectrums of transmitted and received signal. From this figure, we can find that a high frequency components are degraded. In a nondirected wireless lightwave channel, a multipath delay drags on even if the bit rate of a signal is high compared

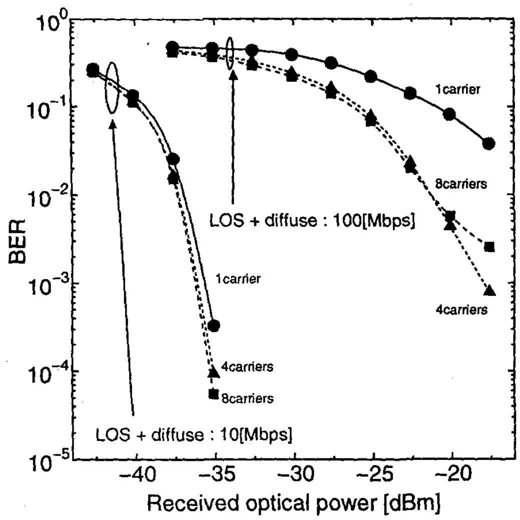

Fig. 9 Multiple-subcarrier transmission effects: FOV at a receiver = 55[deg.], LOS + diffuse channel.

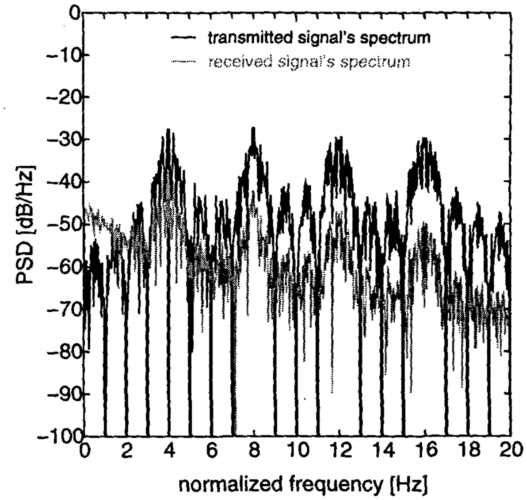

Fig. 10 Frequency spectrum of transmitted and received signals in multiple-subcarrier case (4 subcarriers), FOV at a receiver = 55[deg.]: frequencies are described by a unit of the symbol rate of transmitted signal.

with the delay spread of a multipath channel. The lightwave reflection is differ from the radio wave one. In the radio wave reflection, reflecting elements typically produce specular reflections. However, reflection of lightwave radiation by most surfaces in typical rooms is predominantly diffuse. This difference of these two types of reflections must be considered.

Therefore it is important that we design the FOV of a receiver and the arrangement of lighting equipment so that diffuse paths are not generated.

5 CONCLUSION

In this paper, we have proposed that lighting equipment using white colored LEDs are applied to the access points in wireless home link. White colored LEDs are paid much attention to. High power lighting equipment makes it possible to communicate in the whole room and it is easy to install and looks nice.

The received power at a receiver is calculated from numerical analysis, and this leads the conclusion that it is important to consider the field of view at a receiver in the proposed system. The performance of the proposed system is considered from computer simulation and the relation between the performance and the optical link parameters has been discussed. It has been found that first of all the proposed system can be used in most part of the assumed room when the data rate is 10[Mbps], whereas various subjects should be considered to actualize this system:

- Higher bit rate should be achieved.
- The arrangement of lighting equipment and the design of a FOV of a receiver must be considered.

Now, we are studying the above themes.

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