Chapter

Healthcare Application-Oriented Non-Lambertian Optical Wireless Communications for B5G&6G

Jupeng Ding, I. Chih-Lin and Jiong Zheng

Abstract

With the continuous improvement of user communication requirements and the rapid development of information services, optical wireless communication (OWC), which has unlimited bandwidth and precise positioning, is widely used in indoor scenes such as healthcare. For healthcare monitoring application, the optical wireless (OW) link using non-Lambertian emission pattern is investigated in the typical mobility scenario. Numerical results show that the potential gain could been provided by the concerned emission pattern to the OW performance uniformity.

Keywords: optical wireless communications, non-Lambertian beams, B5G&6G

1. Introduction

With population aging is emphasized around the world, more attention is paid to the development of the healthcare application with new paradigm. Nevertheless, most of the current health application is based on conventional radio frequency (RF) techniques, such as WiFi (Wireless Fidelity) or UWB (Ultra-Wide Band), and the annoying interference issue frequently degrades the user experience. On the other side, the emerging solid source based optical wireless (OW) technology is consistently investigated to complement the wireless capacity for various healthcare application in EM (electromagnetic) sensitive scenarios [1–5]. Specifically, the validity is examined to achieve the diffuse OW communication between the on-body nodes [6–10].

Up to now, the works of OW healthcare system are still limited to the well-known Lambertian emission pattern which is quite consistent with the conventional solid state sources e.g. LED (Light Emitting Diodes) [11–15]. Nevertheless, there are a number of variations following non-Lambertian emission pattern is still waiting for discussion. In this paper, the typical non-Lambertian OW links is explored in typical healthcare scenario, as shown in **Figure 1** for the first time. And the healthcare OW channel gains comparison are made between the Lambertian & the non-Lambertian configuration.

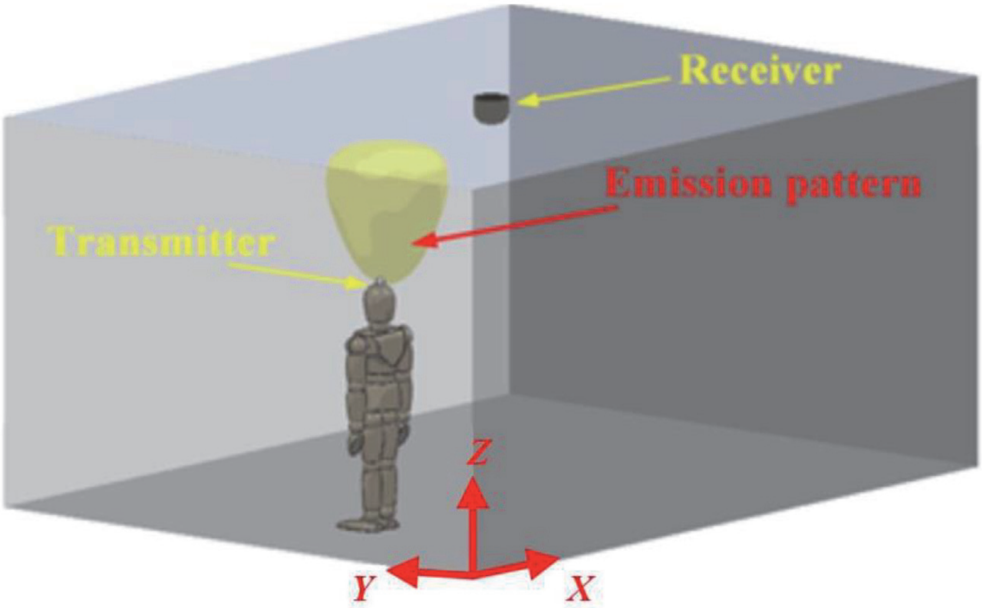


Figure 1.
Typical indoor mobile healthcare scenario.

2. Indoor optical wireless application for healthcare scenario

In this part, the typical non-Lambertian OW links is explored in typical healthcare scenario, as shown in **Figure 1** for the first time. And the healthcare OW channel gains comparison are made between the Lambertian & the non-Lambertian configuration.

2.1 Lambertian & non-Lambertian emission pattern

To the best of our knowledge, in the indoor medical related system shown in the radiation intensity of the transmitter is modeled by the generalized Lambertian pattern as [1, 2]:

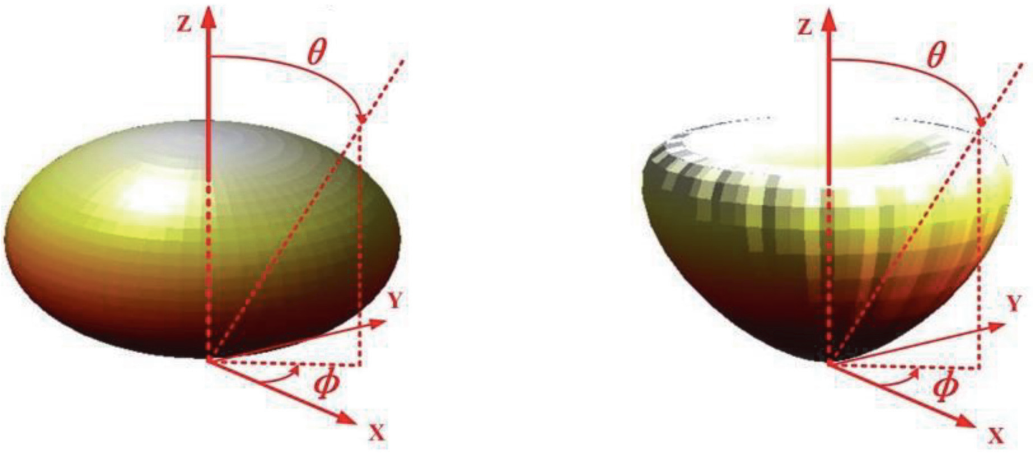
$$I_L(\theta) = \frac{m_L + 1}{2\pi} \cos^{m_L}(\theta), \tag{1}$$

where m_L is the Lambertian index and θ is the elevation angle, as shown in **Figure 2a**. At the same time, due to the distinct manufacture process of the solid sources, there are many optical sources could not be characterized by the mentioned Lambertian emission pattern. Typically, one non-Lambertian pattern of the commercially available product i.e. LUXEON® Rebel from Lumileds Philips is presented in **Figure 2b** for comparison.

Following the work of [3, 4], the radiant intensity of this non-Lambertian type could be expressed as:

$$I_{NL}(\theta) = \sum_{i=1}^{2} g_{1i} \exp\left[-\ln\, 2\left(\frac{|\theta| - g_{2i}}{g_{3i}}\right)^2\right] \tag{2}$$

where $g_{11} = 0.76$, $g_{21} = 0°$, $g_{31} = 29°$, $g_{12} = 1.10$, $g_{22} = 45°$, $g_{32} = 21°$. Obviously, like the Lambertian case, the intensity is independent of the azimuthal angle Φ which basically dominates its symmetry in the far field.



(a) (b)

Figure 2.
3D spatial emission patterns in (a) Lambertian type and (b) typical non-Lambertian type.

2.2 Optical wireless link characteristics comparison

In typical indoor healthcare scenario, the OW channel gain form the optical transmitter on the patient to the optical receiver on the ceiling center could be expressed as [1, 2]:

$$H_L = \begin{cases} \frac{(m_L+1)A_R}{2\pi d_0^2}\cos^{m_L}(\theta)\cos\psi & \psi < FOV \\ 0 & \psi \geq FOV \end{cases} \tag{3}$$

where A_R is the effective receiver area, d_0 is the direct distance from source to optical receiver, and ψ is the angle of incidence on the receiver location. FOV is the field of view of the optical receiver. At the same time, the OW channel gain of the described non-Lambertian emission pattern could be derived as:

$$H_{NL} = \begin{cases} \frac{A_R}{d_0^2}\sum_{i=1}^{2} g_{1i}\exp\left[-\ln 2\left(\frac{|\theta|-g_{2i}}{g_{3i}}\right)^2\right]\cos\psi & \psi < FOV \\ 0 & \psi \geq FOV \end{cases} \tag{4}$$

For simplifying analysis, the orientation of the optical transmitter is set upward vertically. And the orientation of the optical receiver is set downward vertically. In such situation, emission angle of line of sight (LOS) optical signal equals to the incidence angle at the receiver, i.e. $\theta = \psi$. Such that the optical channel gain of the Lambertian case could be rewritten as:

$$H_L = \begin{cases} \frac{(m_L+1)A_R}{2\pi d_0^2}\cos^{m_L+1}(\theta) & \theta < FOV \\ 0 & \theta \geq FOV \end{cases} \tag{5}$$

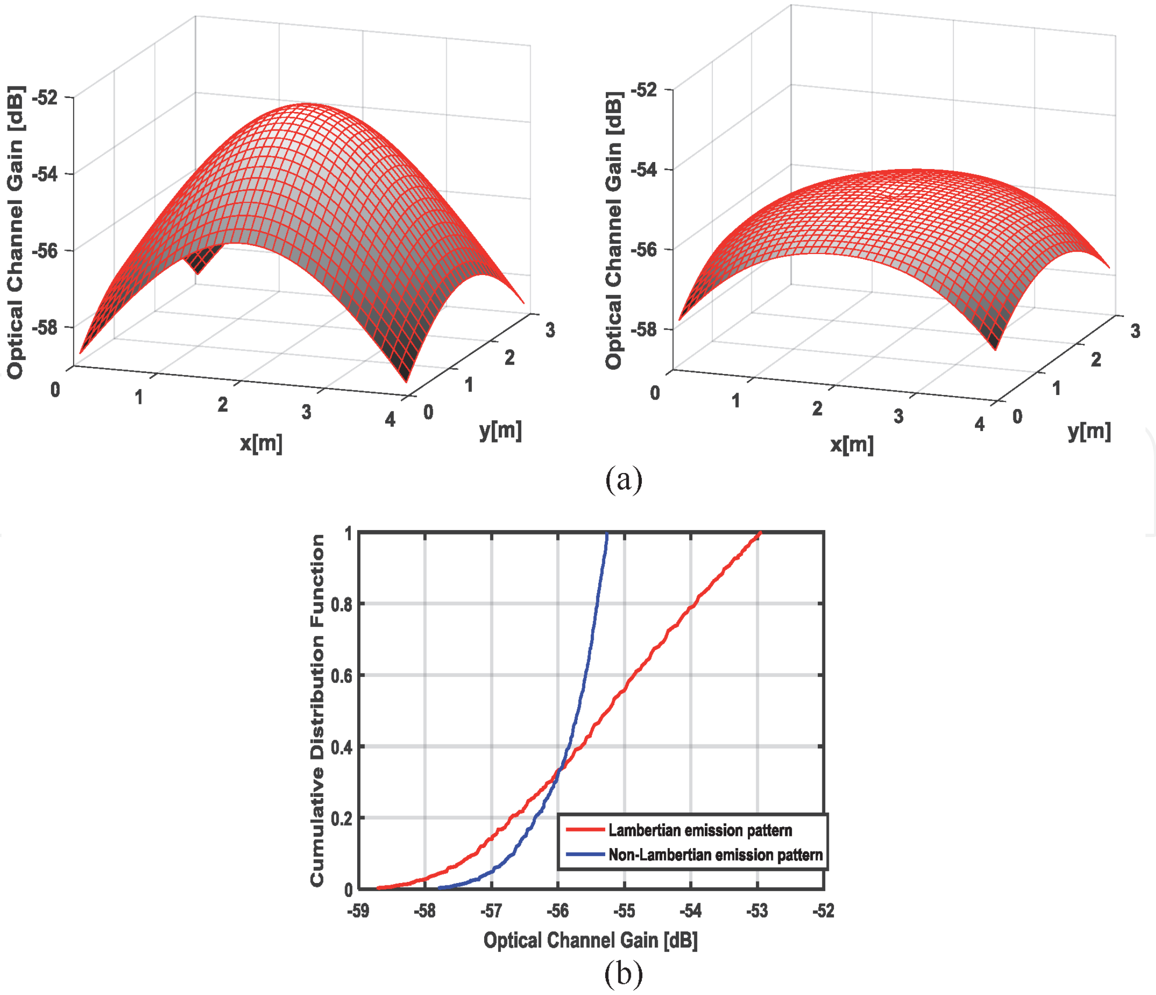
On the other side, the expression of the non-Lambertian pattern channel gain could been simplified as well:

$$H_{NL} = \begin{cases} \frac{A_R}{d_0^2}\sum_{i=1}^{2} g_{1i}\exp\left[-\ln 2\left(\frac{|\theta|-g_{2i}}{g_{3i}}\right)^2\right]\cos\theta & \theta < FOV \\ 0 & \theta \geq FOV \end{cases} \tag{6}$$

For fair comparison, the whole emitted optical power of the both emission patterns are normalized to 1 W. The main parameters for the following simulation are included in the **Table 1**. In this Lambertian pattern case, the mobile patient experiences up to 5.77 dB channel gain variation, specifically ranging from −58.71 to −52.94 dB, as shown in **Figure 3a**. Thanks to the intrinsic spatial emission characteristics of the concerned non-Lambertian pattern, the channel gain ranges from −57.79 to −55.26 dB with variation reduced to 2.53 dB. Accordingly, the performance uniformity brought by the pattern replacement could been observed by the probability distribution function (PDF) in **Figure 3b** as well.

Parameters	**Value**
Length of room	4 [m]
Width of room	3 [m]
Height of room	2.5 [m]
Height of optical receiver	2.5 [m]
Height of optical transmitter	1.8 [m]
Detection area of receiver	1 cm^2
Field of view	85°

Table 1.
Parameters for simulation.



(a)

(b)

Figure 3.
Optical channel gain comparison in (a) spatial distribution and (b) PDF statistics.

3. Conclusion

The high bandwidth, abundant spectrum resources and high confidentiality of wireless optical communication are suitable for 5G and B5G communication systems. With the rapid development of OWC technology, discussions on different beam characteristics and active research will be unprecedentedly released. In this study, the potential channel gain induced by the non-Lambertian beam is investigated in typical healthcare scenario. The results show that the channel gain fluctuation could be reduced up to about 3.24 dB, with constant transmitted optical power.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Jupeng Ding[1]*, I. Chih-Lin[2] and Jiong Zheng[1]

1 Key Laboratory of Signal Detection and Processing in Xinjiang Uygur Autonomous Region, School of Information Science and Engineering, Xinjiang University, Urumqi, Xinjiang, China

2 China Mobile Research Institute, Beijing, China

*Address all correspondence to: jupeng7778@163.com

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