Optical Wireless
Communication
Conference

Optimizing power allocation for LED-based distributed-MIMO OWC systems

T. E. Bitencourt Cunha[1] and J. M. G. Linnartz[1,2]
[1]Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands
[2]Signify (Philips Lighting) Research, 5656 AE Eindhoven, The Netherlands
{t.e.bitencourt.cunha, J.P.linnartz}@tue.nl, j.p.linnartz@signify.com

The Internet is not only accessed by computers and smartphones. With the rise to the Internet-of-Things (IoT), a very wide variety of smart objects can be connected to the Internet. Today, there are already billions of wearables, sensors, televisions, medical and industrial machines, and other devices. Moreover, many new data-hungry applications have been or are being developed, such as Virtual Reality (VR), augmented reality (AR), high-definition video streaming and Industry 4.0. The rapidly progressing technology greatly increases the flow of data across our wireless networks. In future, much larger traffic flows are expected, so this puts pressure on the development of communication systems that must satisfy the requirements of the new technologies used massively by the many users or by autonomous devices.

Today in wireless radio communication, many digital wireless services share the same part of the electromagnetic spectrum. If many devices connected wirelessly to the internet simultaneously send signals through the same communication medium, congestion occurs. This deteriorates the quality of service. Research to develop improved wireless communication technologies has moved from boosting throughputs, i.e., increasing the number of bits/s, towards systems that provide densification, i.e., many bits/s/m^2. Therefore, data volume per area became a key performance measure.

To achieve better management of interference among nearby radio frequency (RF) access points, and to densify the system, research in RF technologies has moved towards the use of shorter wavelengths, thereby achieving very small cells. The use of carriers in the THz frequency range is a promising technology for 6G [1]. Extending the choice of higher carrier frequencies further, optical wireless communications has also attracted more and more attention. As the optical signals stays confined between walls, as most of the optical signal energy stays in the line-of-sight (LoS) link, and as light propagation allows the use of small cells, optical wireless communications (OWC) is a logical path for the design of tiny coverage area cells [2]. In addition, OWC also enhances the security at the physical layer as the signals transmitted using light cannot be intercepted outside the room. Therefore, OWC is seen as a solution complementary to

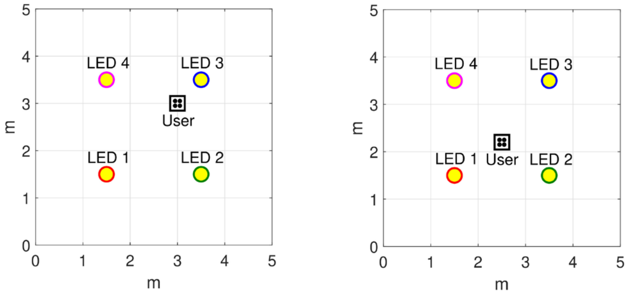
RF, which helps to alleviate the spectrum crisis. To cover a large area, many light sources can be used in parallel, as it has already been used nowadays to provide uniform illumination. The use of multiple spatially distributed emitters also demystifies the myth that communication is over if the LoS link is blocked [3]. In fact, the transfer of bits can continue via other paths, from other emitters.

To accelerate mass market adoption, LiFi system designers have considered the use of inexpensive light-emitting diodes (LED)s. LEDs have taken over the illumination market and, nowadays, are present in almost all places where artificial lighting is required. However, some challenges must be overcome for designing high-speed data transmission systems using these. Firstly, the LED quantum well creates a first-order low-pass effect and, thus, the bandwidth of the output optical signal is limited, typically at few tens of MHz. If a higher bandwidth is required, it is possible to somewhat speed up the LED response by increasing the DC current density, but it has the cost of a reduction on the efficiency at which a current modulation translates into an optical signal [4]. LED performance is also temperature sensitive. A rise in the temperature of the junction induces a signal-to-noise ratio degradation [5]. Overdriving the LED to achieve higher bandwidth has then undesirable consequences, as the temperature of the junction is anyhow dependent on the current that goes through the LED. When the current is large during a prolonged period, the high current densities can significantly shorten the useful lifetime of the device. LEDs are thus limited in power. To exploit its best performance and provide reliable signal transmission for a long time, their power limitation must be respected.

The simultaneous transmission of multiple signals through multiple emitters and multiple receivers using multiple-input multiple-output (MIMO) schemes help to improve performance against the low-pass channel by exploring the MIMO multiplex gain [6]. Using orthogonal-frequency-division-multiplexing (OFDM), multiple independent subcarriers are simultaneously transmitted over the low-pass frequency response of every LED. OFDM allows the use of power loading strategies for finding the best power-spectrum density for throughput improvement [7]. Although the combination of MIMO and OFDM has been widely explored in literature, the study of power allocation strategies respecting the fact that LEDs are limited in power is still in the beginning [6] [8] [9].

One aspect is that in radio communication the channel crosstalk matrix highly depends on frequency and on the position of the antenna. Due to Rayleigh or Rician multipath reception, the channel response and the crosstalk values change if antennas are moved over half a wavelength or if the (subcarrier) frequency is changed over more than the coherent bandwidth. So, the communication overhead to negotiate adaptive power and bit loading is excessive and has been a reason to not rely on full channel state information in many radio standards. Yet, for OWC this dramatically changes as the channel may be described in a frequency independent crosstalk concatenated with the stream-independent frequency response of electro-optical conversion [6] [10]. In this paper we use such a model and assume full channel state information at the transmitter.

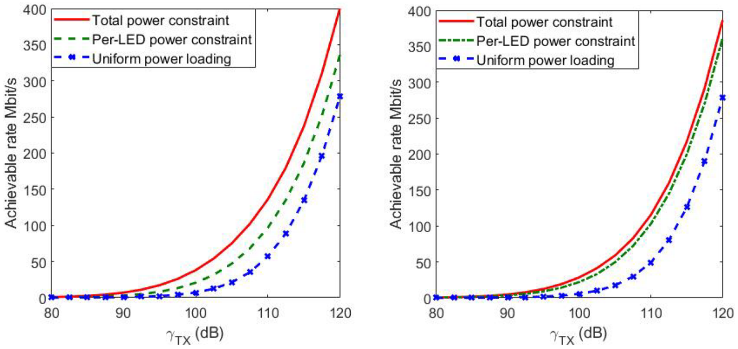
Another aspect is the power constraint. In [6], it has been shown that a MIMO power optimization under a total-power constraint, thus one that allows power exchange among the LEDs leads to unrealistic solutions. In this work we consider two different scenarios, as shown in Figure 1.



a) Scenario 1 b) Scenario 2

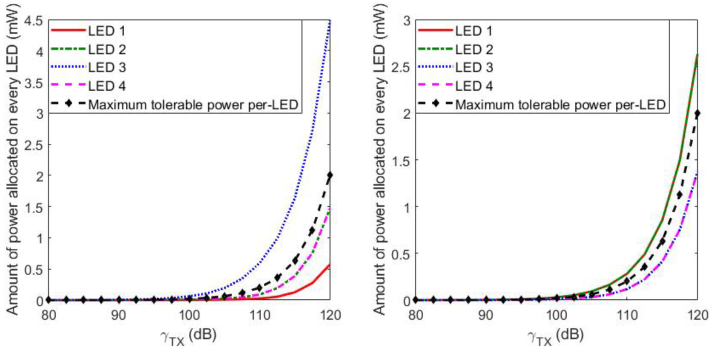
Figure 1: Illustration of the two 4x4 LED-based D-MIMO OWC system considered scenarios.

In Figure 2 the performance achieved by three different power allocation strategies is shown for each scenario [6]. It is then clear that the commonly used total power constraint, i.e. a constraint equal to the sum of the amounts of power supported by every LED, can lead to a higher throughput. However, it is unrealistic: As shown in Figure 3, these solutions may overload, thus damage the LEDs that are closest to the user.



a) Scenario 1 b) Scenario 2

Figure 2: Throughput achieved by a 4X4 LED-based D-MIMO OWC system in the two analysed scenarios.



a) Scenario 1 b) Scenario 2

Figure 3: Amounts of power allocated on every LED when performing a power allocation optimization under a total power constraint.

To achieve solutions that can be used in practice, a per-LED power constraint is imposed to the optimization problem. As expected, these perform less than an overly optimistic assumption of a total power constraint [6].

Yet, an optimized power and bit loading achieves higher performance than spreading power uniformly over the total system bandwidth as illustrated by the ‘Uniform power loading’ curve. Although their solutions help us better understand the system performance, the optimization problems were solved using the software package CVX, which is heavy in terms of computational complexity. Thus, it is hard to embed it in future generations of LiFi chipsets. To improve LiFi experience, new realistic and computationally efficient power loading strategies are needed.

References

[1] W. Saad, M. Bennis and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," *IEEE Network,* vol. 34, no. 3, pp. 134-142, 2020.

[2] H. Haas, L. Yin, Y. Wang and C. Chen, "What is LiFi?," *Journal of Lightwave Technology,* vol. 34, no. 6, pp. 1533-1544, 2016.

[3] T. Fath and H. Haas, "Performance Comparison of MIMO Techniques for Optical Wireless Communications in Indoor Environments," *IEEE Transactions on Communications,* vol. 61, no. 2, pp. 733-742, 2013.

[4] J. -P. M. G. Linnartz, T. E. B. Cunha, D. V. Romero and X. Deng, "Throughput optimization for IR-LEDs in an optical wireless link," in *ICC 2022 - IEEE International Conference on Communications*, 2022.

[5] H. Chen, A. T. L. Lee, S. -C. Tan and S. Y. Hui, "Electrical and Thermal Effects of Light-Emitting Diodes on Signal-to-Noise Ratio in Visible Light Communication," *IEEE Transactions on Industrial Electronics,* vol. 66, no. 4, pp. 2785-2794, 2019.

[6] T. E. B. Cunha, J. -P. M. G. Linnartz and X. Deng, "Achievable rate of LED-based distributed MIMO OWC systems under a per-LED power constraint," in *2021 17th International Symposium on Wireless Communication Systems (ISWCS)*, 2021.

[7] S. Mardanikorani, X. Deng and J. -P. M. G. Linnartz, "Sub-Carrier Loading Strategies for DCO-OFDM LED Communication," *IEEE Transactions on Communications,* vol. 2, no. 68, pp. 1101-1117, 2020.

[8] Y. Zeng, J. Wang, X. Ling, X. Liang and C. Zhao, "Joint precoder and DC bias design for MIMO VLC systems," in *2017 IEEE 17th International Conference on Communication Technology (ICCT)*, 2017.

[9] J. Lian, Y. Gao, P. Wu, G. Zhu and Y. Wang, "Indoor MIMO VLC systems using optical orthogonal frequency division multiple access," *Optics Communications,* vol. 485, 2021.

[10] J. P. Linnartz et al., "ELIoT: New Features in LiFi for Next-Generation IoT," in *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2021.