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

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The Internet is not only accessed by computers and smartphones. With the rise of the Internet-of-Things (IoT), a very wide variety of smart objects can be connected. Today, there are already billions of wearables, sensors, televisions, medical and industrial machines, and other devices connected to the network. 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 in 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 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., increase 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 then increase densification, research in RF technologies has moved towards to 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. Due to many reasons, such as the optical signals stays confined between walls and most of the optical signal energy stays in the line-of-sight (LoS) link, 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 complementary solution 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 (LEDs). LEDs have taken over the illumination market and, nowadays, are present in almost all places where artificial lighting is required. These can be reused for communication [4]. However, some challenges must be overcome for designing high-speed data transmission systems using them. 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 a few tens of MHz [5]. 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 [6]. LED performance is also temperature sensitive. A rise in the temperature of the junction induces a signal-to-noise ratio degradation [7]. 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 density is large during a prolonged period of time, it can significantly shorten the useful lifetime of the device. LED devices are thus limited in power. To exploit their 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 exploiting the MIMO multiplex gain [8]. Using orthogonal-frequency-division-multiplexing (OFDM), multiple independent subcarriers are transmitted simultaneously 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 [9]. Although the combination of MIMO and OFDM has been widely exploited in literature, the study of power allocation strategies considering the fact that LEDs are limited in power is still in the beginning [8] [10] [11].

One aspect is that in radio communication the channel crosstalk matrix highly depends on frequency and on the antenna position. 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 not to rely on full channel state information in many radio standards. Yet, for OWC this dramatically changes as the channel may be described with a frequency independent crosstalk coefficient concatenated with a stream-independent frequency response of electro-optical conversion [8] [12]. In this paper we use such a model and assume full channel state information (CSI) at the transmitter.

Another aspect is the optimization power constraint. In [8], it has been shown that a MIMO throughput optimization under a total-power constraint, thus one that allows power exchange among the LEDs leads to unrealistic solutions. As the strongest channels comes from the closest LEDs to the user, the algorithm tries to push as much power as possible on those LEDs to maximize performance. The issue is that the amount of allocated power on those LEDs can be much higher than the power limitation of the device. To illustrate this, we considered a scenario where the user is placed close to one of the LEDs as shown in Figure 1.

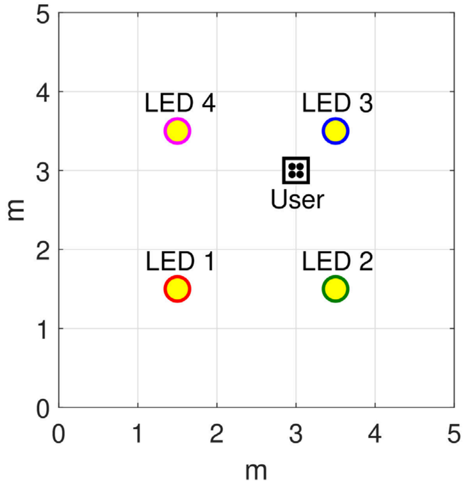

Figure 1: A 4x4 LED-based D-MIMO OWC system with an user placed close to one of the LEDs.

In Figure 2 we plot the throughput achieved by the system when performing different power loading strategies and for different link power budgets. It is clear in Figure 2 that the commonly used total power constraint leads to higher throughput. However, it leads to an unrealistic solution. In Figure 3 we show the amount of power allocated on every LED for the optimization under a total power constraint. The amount of power allocated on LED 3 is far beyond its maximum tolerable amount of power. Thus, in consequence, this solution may damage the closest LEDs to the user, it may lead to thermal issues, or it may experience issues with clipping or possible non-linear distortions.

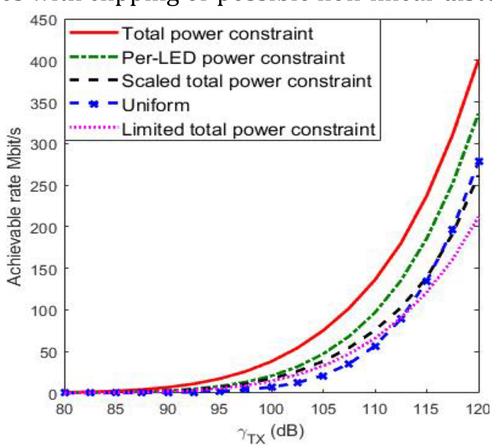

Figure 2: Throughput achieved by a 4X4 LED-based D-MIMO OWC system in the considered scenario.

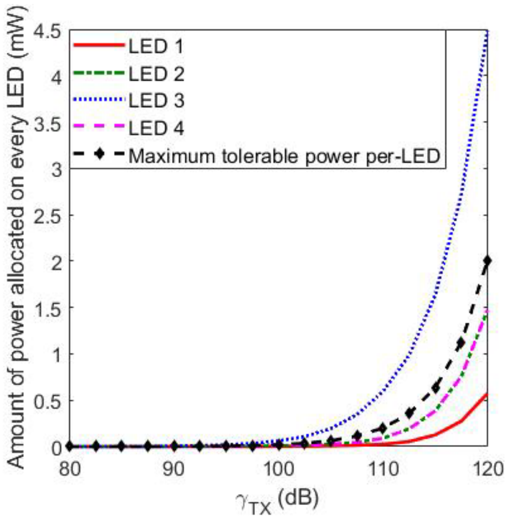

Figure 3: Amount of power allocated on every LED when performing a power allocation optimization under a total power constraint.

To achieve solutions that can be used in practice, in the approach “Limited total power constraint”, we reduce the amount of power shared among the LEDs to a value equal to the maximum amount which can be tolerated by only one LED. By this way, it is guaranteed that no LED will be overloaded, but performance decreases significantly. It is possible to scale the total amount of power shared among the LEDs iteratively till a certain amount at which throughput is maximized but no LED is overloaded. This strategy is done in the approach “Scaled total power constraint”, but it shows to not be effective as well. The “Uniform” loading strategy consists of uniformly spreading power over the space and frequency components of the channel. In a way that the power allocated on each OFDM subcarrier is the same for all MIMO subchannels. This approach is commonly used in RF systems when it is not possible to have CSI at the transmitter. However, due to the low-pass response of the LED, the uniform approach shows to not achieve a satisfactory performance as well.

A per-LED power constraint is then imposed to the optimization problem. As expected, this approach achieves lower throughput than an overly optimistic assumption of a total power constraint. Yet, an optimized power and bit loading achieves higher performance than spreading power uniformly over the total system bandwidth. Although these solutions help to better understand the system performance, the optimization problems were solved using the software package CVX, which is heavy in terms of computational complexity, and thus, it is hard to imbed in future generations of LiFi chipsets. Realistic and computational efficient power loading strategies are then required for improving LiFi experience.

This paper will give an overview on recent results and an outlook towards improved algorithms.

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