Performance Evaluation of Beam Steering using Piezoelectric Actuators.

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Abstract

Optical wireless communication (OWC) has been considered the technology of choice to realize ultra-high bitrates and low latency for wireless communication. Therefore, we have the objective to develop an optical transmitter capable of serving an indoor area, meaning that it must track and connect to multiple nomadic users. A narrow light beam delivers the best power to the receiver, but because of its size, it must be steered to the receiver aperture. We are part of the NWO optical superhighways project, under grant 12128 Optical Wireless Superhighways: Free Photons.

One of the proposed solutions is the use of a pair of piezoelectric actuators coupled with an optical fiber. By controlling each actuator, we can achieve two-dimensional freedoms of movement. Steering the beam with this method is done by decentralizing the fiber from the center of the magnifying lens. This is challenging, due to the limited movement of the actuator, consequently, the lenses must be in the micrometer dimension. This system has been simulated with results of a steering beam angle of around 10 degrees. Furthermore, the lenses are being designed and will be produced for a practical experiment.

Introduction

Current data consumption grows at an exponential rate, and so overloads the wireless network infrastructure. These networks are limited due to the legally defined frequencies and the overcrowding of them by the huge number of users, this is also a consequence of the expansion of the internet-of-things (IoT) [1]. As a possible solution for the end-user congestion, we propose the use of OWC technology, which will offload the RF frequencies [2]. Optical communication also has the advantages of having huge bandwidths, low latency, high privacy, and low interference from neighboring networks.

To develop this novel indoor network, we are proposing a transmitter that must track and connect to multiple users. The data throughput is defined by the laser bandwidth and the power delivered to the receiver, therefore, to have the best data throughput it is necessary to deliver the maximum power to it. But, due to eye safety concerns [3], the beam power must be maintained below a certain threshold. Therefore, it is not possible to illuminate the whole room and get the desired signal to the receiver. Then a narrow light beam is a solution that delivers high levels of power to the receiver while maintaining the power in a safe zone [4]. But, because of its size, the beam must be steered to the receiver aperture.

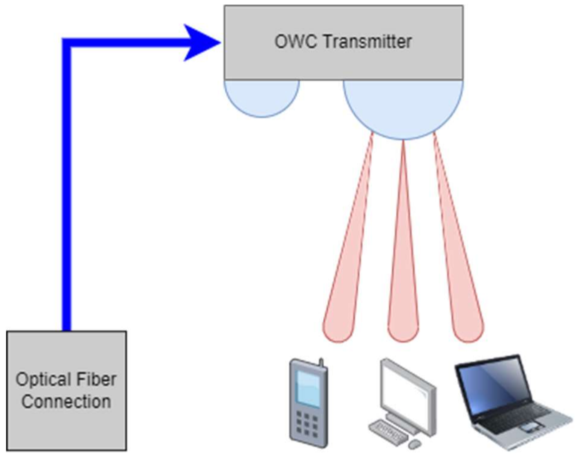

Figure 1 OWC Indoor concept

For the construction of a feasible OWC network, the transmitter must fulfill many requirements such as multi-beam capability, 2D steering, a wide field of view, and large throughput. For these requirements, many viable solutions can be found for beam steering, such as Array Waveguide Gratings [5], Micro Electrical-Mechanical systems [6], Meta-Surfaces [7], Optical Phased Arrays [8], Polarization Gratings [4], Spatial Light Modulators [9].

This paper intends to give an overview of technologies used in a beam steered OWC transmitter. This is an extensive field, as previously commented, with several workable solutions. All the technologies can, in some form, fulfill the requirements for the OWC, and the most advanced now is the use of a pair of piezoelectric actuators to steer the beam. After discussing the concept of the beam steering transmitter concept, I will demonstrate a simulation and show the design of a future experiment. This work is supported in part by the Netherlands Organization for Scientific Research (NWO) under grant 12128 Optical Wireless Superhighways: Free Photons.

System Concept

To keep the costs and time-to-market down, we will utilize the most from the standard fiber communications and adapt it to an indoor OWC system. And because of its wide implementation, we will be using the 1550nm C-band communication equipment as the base for this project. The basic concept is that we need to serve an optical signal, with enough quality to keep the data throughput, to individual users. At the same time tracking its movements and updating the localization to the steering control.

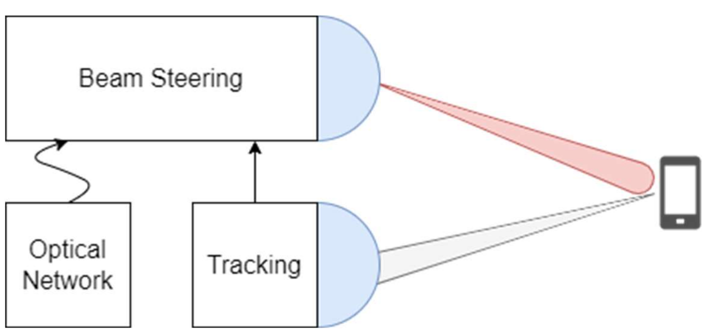

Figure 2 Beam-steering system diagram

Figure 2 is the basic scheme of our transmitter. The tracking module has the responsibility to track and separate each user and update this data to the beam steering control unit. Then, with the localization information each beam is moved to the receiver aperture of a user. Following the system requisites, the steering unit must steer multiple beams or be small enough where many units can work in parallel in a single transmitter. Also, there are several ways of sending signal to the transmitter, such as, multiple optical cables, multicore fibers, or a multiplex signal split with an AWGr, separating the wavelengths for different the users.

A pair of piezoelectric actuators, each controlling one axis of movement, is a solution to the steering problem. Because they fit the prerequisites, while being small enough to be implemented in parallel, and having a good steering angle in 2D. The actuators steer a beam by moving the source of the light, here being an optical fiber. But, to have several parallel elements in the same transmitter, with each responsible for one user, the actuators are small. And because of their size, the actuators have a limited range of movement, in the micron range. Therefore, there is the need to amplify this tiny move to a usable larger area of service. We can achieve this magnification by using a lens in the same size range as the movement, this means that we also need a lens in the µm range.

Simulation

The simulation was designed to demonstrate beam steering using actuators. This is done by moving the output of a standard optical fiber from the center of a fixed lens [10]. In this manner the lens acts as an angle magnifier, amplifying the tiny movement from the actuators into a more useful angle. The microlenses and their modeling were investigated and manufactured in [11].The system was simulated in Optical Studio 16, using a model of a polymer microlenses on a silicon substrate, the lens has a radius of fifty µm and a focal length of 111 µm. After the initial setup, the fiber output was moved to its maximum extension of twenty µm, in steps of 2.5 µm.

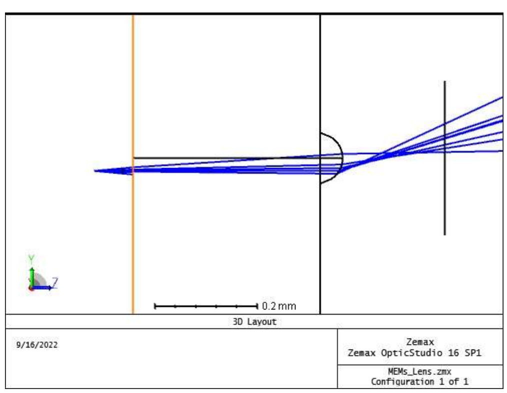

Figure 3 Lens setup

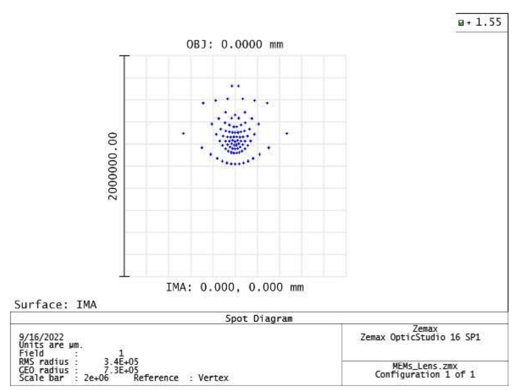

Figure 4 Cross section of rays at 1m from the output

Figure 3 shows the elements being simulated using raytracing, the first element is the output of an optical fiber, which is simulated as a Gaussian beam. This beam then goes through the silicon substrate that has a thickness of 410µm, then, hits the microlenses with a determined offset of 20 µm in the figure. This offset, in conjunction with the lens focal length, will determine the total deflection angle of the optical beam. Figure 4 is the cross-section of the ray-traced beams at a target at 1m from the lens, this is useful to calculate the beam angle of deflection and angle of dispersion.

As expected by moving the fiber from the center of the lens the output beam is steered. At the end of propagation, we achieved a deflection angle of 12 degrees and an angular dispersion of 36 degrees. This simulation also showed that the system is limited not only by the movement of the actuators but also by the size of the lens. A smaller lens has a smaller focal lens, therefore increasing the deflection angle. But at the same time the closer the beam gets to the edge of the lens; the greater distortion will happen at the target.

With the simulation results in hand, we will continue to a proof-of-concept experiment using the same setup simulated. Using a pair of voltage-controlled actuators to move the fiber against a grid of lenses with several varied sizes, thus giving the ability to evaluate multiple focal lengths in the same setup. And using an IR camera as the target to measure the resulting steering.

Conclusion

In the development of an OWC indoor network, it was concluded that there is a need for a form of beam steering to deliver the best signal to the receiver. As part of the research, several active forms of beam steering were observed to be capable of meeting most of the requirements set for the system. The most advanced system at hand was the one that steered the beam with the use of a pair of actuators. As a primary evaluation, a simulation in Optical Studio was made, with results in the expected range of angle magnification, therefore justifying the advancement of this method to a real experiment.

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