Auto-Configurable Optical Linking Modules for Mobile Free Space Optical Communications

Chang Liu, Jayasri Akella, Chingpo Chen, Murat Yuksel, Shiv Kalyanaraman, Partha Dutta

***Abstract*— Existence of line of sight (LOS) and perfect alignment between the communicating modules is one of the key requirements for free space optical communication. To ensure uninterrupted data flow, auto-aligning transmitter and receiver modules are necessary. We propose a new approach based on spherically shaped transmitter and receiver modules (optical antenna) for maintaining optical links even when the two modules are in relative motion. The spherical optical antenna provides angular diversity in 3-dimensions, and hence provides a line of sight at any orientation as long as there are no obstacles between the two communicating modules. To demonstrate the proof-of-concept, we designed and tested an auto-configurable circuit integrated with light sources and detectors placed on spherical surfaces. Communication between a stationary and a mobile optical antenna has been demonstrated.**

***Index Terms*— Free Space Optical communication, Auto-Configurable, Angular Diversity.**

I. Introduction

OPTICAL wireless, also known as free space optics (FSO), is an effective high bandwidth communication technology serving commercial *point-to-point* links in terrestrial last mile applications and in infrared indoor LANs [1][2][3][4] [5][6][7]. FSO has several attractive characteristics like license-free band of operation, dense spatial reuse, low power usage per transmitted bit, and relatively high bandwidth. Current FSO equipment is targeted at point-to-point links using high-powered lasers and relatively expensive components used in fiber-optical transmission. Mobile communication using FSO are being employed in indoor environments, within a single room, using diffuse optics technology [1][9][10][11][12]. These techniques are suitable for small distances (typically 10s of meters) due to limited power of a single source that is being diffused to spread in all the directions. For outdoors fixed FSO communications, techniques to counter mobility caused by small vibrations and swaying of the buildings have been implemented using mechanical auto tracking. One of the major limitations of FSO is the line of sight maintenance for continuous data flow. In this letter, we introduce the concept of a spherical optical antenna that provides angular diversity and hence line of sight in 3-dimensions. We have used multiple optical transceivers tessellated on the surface of a sphere. Tessellation also improves the range characteristics because every direction now has a light source (an LED) whose operating range is typically a few hundred meters. We designed an auto-configurable circuit that makes use of this "angular diversity" to maintain continuous line of sight between two communicating optical antennas even when they are mobile and demonstrated the mobility in a two-node proto-type experiment. To the best of our knowledge, this is the first time spatial and angular diversity coupled with electronic tracking for "mobile" communications using free space optical technology is being reported.

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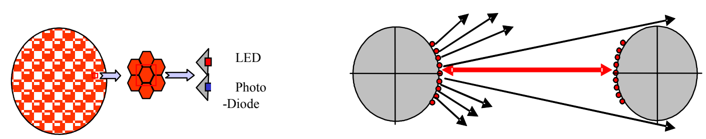
II. Concept of Tessellated Spherical Optical Module

The very geometrical shape of a sphere suggests spatial and angular diversity. We tessellated the surface of the sphere using optical transceivers. Each transceiver contains an LED (Light Emitting Diodes) as the transmitter and a photo diode as the receiver. Since LED has a relatively high divergence angle and the photo detector (PD) has a comparable angular field of view, the LED-PD pair forms a transceiver cone. This cone covers a significant volume of 3-dimensional space. By tessellating the sphere to an appropriate density we can cover entire 360 steradian of the surrounding space. The sphere with tessellated transceivers is shown in the Figure 1(a).



a) Tessellated Sphere (b) Showing a Line of Sight

Fig1: Sphere tessellated with LED+PD transceivers.

As seen from the Figure 1(b), there is always a line of sight present between the two spheres. When the spheres move relative to each other, an existing line of sight between them is lost and a new one is established. We designed an auto-configurable circuit that latches on to the new line of sight by monitoring light signals sent by the two spheres.

III. Auto Alightment Circuit Design and Testng

The basic functionality of the auto-aligning circuit is to monitor the line of sight between the two communicating

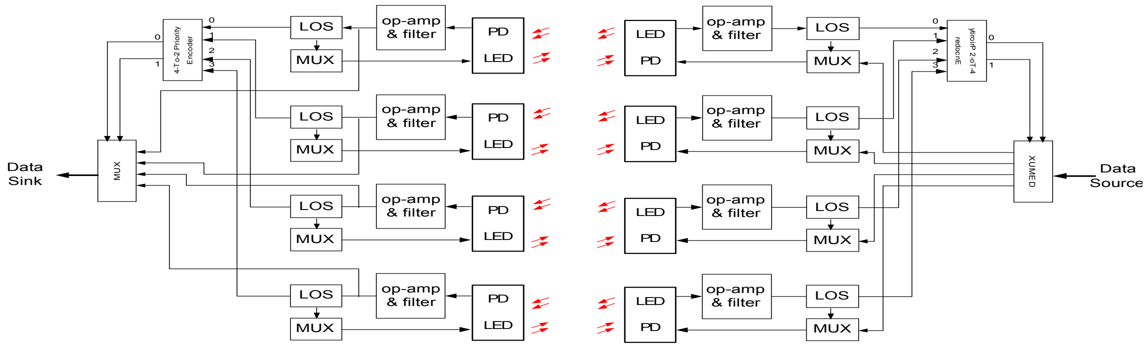
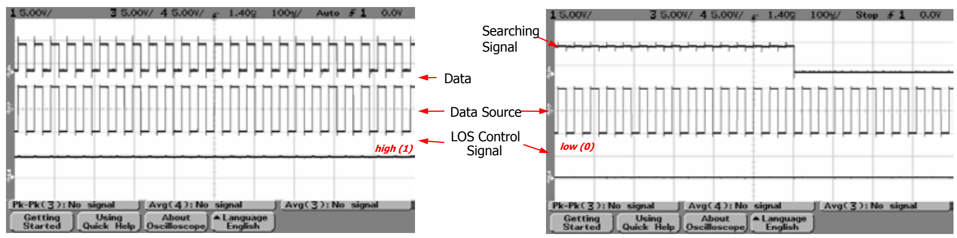


Fig 2: Schematic of the auto-alignment circuit with 4 channels circuit.



(a) Aligned: LOS output is high (1),
Data is sent out during this phase

(b) Misaligned: LOS output is low (0),
Searching signal is sent out

Fig 3: Signals from the auto-alignment circuit.

optical antenna and latch dynamically on to an existing line of sight between them.

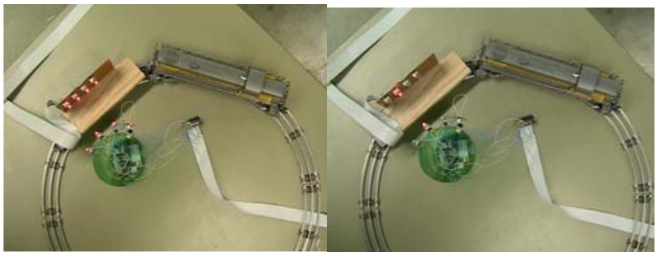
In Fig 2, the schematic of the circuit for two optical antennas, with four transceivers each is shown. In the event of misalignment, the circuit first searches for an existing line of sight between the two spheres and once a line of sight is established, the circuit continues data communication through the new line of sight. These two functionalities are central to the whole auto-alignment process and are implemented in a common hardware for all the transceivers on a single spherical optical antenna. The part of the circuit that monitors an existing line of sight is shown as the "LOS detection". This LOS detection unit gives out a logical high output when a line of sight is present between the two communicating antennas and a logical low input when the line of sight is lost. The logical low output triggers the "LOS searching". During this phase, data transmission is temporarily aborted and search pulses are sent out in all the directions looking for line of sight. The second sphere, which now moved to a different spatial location also looses line of sight and hence it too starts to initiate LOS searching. Spheres eventually receives these search pulses, since both the optical antenna are in continuous motion. This causes the "LOS Detection" to give a high output since the line of sight is again established. At this point again data transmission between the two spheres is restored. The logical output from the LOS detection unit controls the multiplexer and de-multiplexer and channels the data appropriately.

A priority decoder is used as a channel selecting mechanism by using the LOS signal obtained from auto-alignment circuit elements in the case when multi-channels are aligned. When no channel is aligned, the system searches for alignment by sending pulses to each channel. As soon as one or more channels get aligned, it starts to send data signal out through the aligned channel. Thus, the logical data channel (or stream) is assigned to the physical channels dynamically depending on whether or not they are aligned. The LOS detection is implemented using a half-wave rectifier circuit. Whenever the photo detector receives alignment searching pulse, the rectifier will convert the signal into logic high. The output of this rectifier will be an enable signal for a 2-1 multiplexer. The multiplexer has one input as a searching pulse, and the other as a binary data source. If the enable signal is high, the output of the multiplexer will be the binary data source, and a zero enable signal will trigger searching pulse. The search pulse is constructed using a 555 timer.

Figure 3 illustrates the signals from the circuit during the alignment and mis-alignment phases. Figure 3(a) shows the signals when the two communicating optical antennas are aligned. LOS signal is "High" (bottom row), and the LED sends out data signals (top row). Similarly, Figure 3(b) illustrates the signals from the circuit when the two antennas are misaligned. LOS signal is "Low", and LED is sending out the searching pulses (top row).

IV. MOBILITY ANALYSIS

To demonstrate the concept of spatial diversity and LOS auto-alignment enabling mobile optical wireless communication we performed a fun experiment. We built a cylindrical and a planar optical antenna with 4 duplex optical channels each. We used LEDs with a divergence angle of 24 degrees and photo-diodes with field of view of 20 degrees to form the optical transceivers. Four optical transceivers are spaced with an equal angular separation of 32 degrees on the cylindrical surface along a circumference normal to the cylinder axis. The plane surface also has four optical transceivers equally spaced along a line and is moved along a circular path (as a part of train's cargo). This set up demonstrates relative mobility along a circular path of radius 30 cm.



(a) (b)

Fig 4: Illustration of the mobility experiment using a train

We placed the cylindrical antenna at the center of a circular train track. The plane surface with optical transceivers is then placed on the train and moved along the circular tracks. The set up is illustrated in the figure 4. Figure 4(a) shows a misalignment caused due to the movement of the train. The search pulses are sent out by all the transceivers, hence we can see all the LEDs are glowing. Figure 4(b) shows that the two antennas are in line of sight with each other and data transmission is going on between them. This pattern repeats as the train travels along the circular path. Fig 5 demonstrates the continuous alignment and misalignment phases as the train moves relative to the cylinder. The two antennas loose alignment at one instant and come into alignment in the next instant as they move relative to each other.

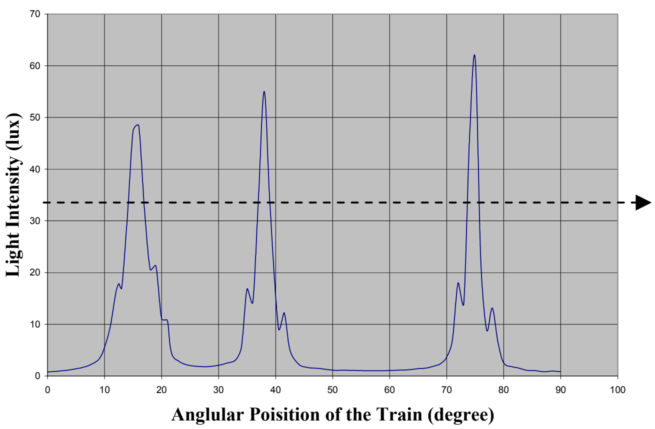


Fig.5 Intensity at the optical antenna as the train moves along the circle.

The dashed line indicates the light threshold used for this set up above which where LOS is high (aligned). The periods where connectivity or line of sight is lost can be minimized by choosing a higher tessellation density. By choosing a appropriate light threshold, LED divergence and PD field of view, we can maximize the alignment periods during the relative motion. The speed of the circuit should be more than the speed of the relative movement between the spheres so as to maintain a smooth data flow.

The set up described here operates on a single data channel and works for two nodes in continuous motion. The mobility experiment is demonstrated for a range over 30 cms, but can be easily extended to 100s of meters since LEDs are known to operate over such large distances. One of the key features of our design is the absence of mechanical parts such as motors or moving mirrors typically used for auto-alignment purpose. This leads to significant savings in power consumption and improved reliability of our modules.

V. Summary

We proposed and developed a new scheme for mobile free space optical communications using spherical surface tessellated with optical transceivers to obtain spatial diversity and an auto-configurable optoelectronic circuit that makes use of this diversity to enable mobility between communicating modules. The auto-configurable circuit monitors the line of sight between two communicating spherical optical antennas, and latches automatically onto existing line of sight points between the two antennas. We built a proto-type system and demonstrated optical data transmission between mobile nodes. The basic techniques can be extended to configurations containing more than two nodes. Detailed analysis of these systems involves issues like optimal transceiver density for desired coverage, size of the antenna, interference etc. and are currently being researched.

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