Abstract

Visible Light Communication (VLC), which uses visible light (400–800 THz) to transmit data, is considered a breakthrough technology catering to the surging demand for high-speed data connectivity. In this thesis, multi-cell indoor downlink VLC system has been studied for performance enhancement. In multi-cell framework, multiple optical atto-cells are strategically deployed to ensure uniform illumination along with efficient data transmission. However, the efficacy of such systems is hindered by a critical issue, inter-cell interference (ICI). ICI results from the overlapping channels of the adjacent atto-cells. This interference leads to poor signal-to-interference-plus-noise ratio (SINR). Additionally, the reliability of VLC depends on the presence of line-of-sight (LoS) links between the access point and the user. Any obstruction in between results in interruption of communication. Moreover, for adaptation of the VLC technology in mass market, the receiver system should be compact in size and integrable with in smart gadgets.

In this context, this thesis primarily focuses on the development of freeform based optical front-end for receiver system. Freeform surfaces have no symmetry around any axis of rotation. It offers more degrees of freedom, also has the ability to accommodate wide field as compared to the conventional symmetrical optics. Use of freeform surfaces reduces number of components and overall size of the system. The rotationally non-symmetric freeform has been proposed in this thesis to develop an off-axis quadrilateral field of view for receiver front-end, which mitigates ICI considerably by spatially separating channels from the adjacent cells.

The first part of the thesis work delved in designing freeform based receiver namely freeform diversity receiver (FDR). FDR has four freeform surface element (FSE) and each of FSE has off-axis FOV. The use of freeform optics reduces the dimension of receiver compared to the other existing multi-cell VLC receivers. The evaluation of the proposed FDR system at different operational conditions has shown it has superior SINR performance. In order to enhance the communication performance further, the receiver architecture is updated with a modified design of FDR (MFDR).

The second stage of the research work deals with the fabrication, metrology and the experimental validation of the previously proposed FSE. Single point diamond turning

(SPDT) machine and profilometry have been used for fabrication and characterization respectively. The effects of FSE form error and roughness on the SINR is evaluated and the findings are used as feedback to the machining process. One receiving unit prototype has been prepared with fabricated profile and experimentally validated on test bench. The research work is further extended to reduce optics size. A novel design of freeform-Fresnel surface has been proposed to replace FSE. The total height of freeform-Fresnel element is much smaller than FSE. The first trial freeform-Fresnel element is fabricated using SPDT and the challenges related to its development and alignment process is reported in this Section. Afterwards, a design of monolithic freeform-Fresnel has been presented with SINR performance. The idea of monolithic profile has eliminated the need of orthogonal alignment of individual element.

This thesis has also explored the utility of emerging reconfigurable intelligent surfaces (RIS) to establish alternating reflected links in the absence of LoS link. RIS is tunable passive elements made of primarily metasurface or mirrors array and has the capability to manipulate the orientation of reflected light in desired direction.

This work also explored the use of RIS in multi-cell environment to enhance communication performance. The SINR performance is studied for different FOV photodiodes (PD) with RIS, no-RIS during blocking and no blocking condition. Integration of RIS has improved SINR on a certain zone on the communication floor even in presence of blockage.

In the final phase of the thesis, the impact of FDR and MFDR, which are mainly off-axis FOV receiver system, have been evaluated during light path blockages in RIS assisted multi-cell indoor system. SINR performance, data rate, coverage probability of PD, FDR, and MFDR have been compared to identify the most suitable receiver system for the aforesaid application. Also, the relationship with RIS quantity, and RIS positions have been studied in presence of different receiver geometries. Finally, the influence of RIS on indoor illumination level has been reported.

The results obtained in this thesis confirm that the introduction of freeform optics and reconfigurable intelligent surfaces are attractive solutions for ICI mitigation and blockage management in multi-cell indoor scenarios.