Ph.D. in Information Technology
Thesis Defense

March 25th, 2025
At 4:00 p.m.
Room Beta – Building 24

Seyedmohammad SEYEDINNAVADEH – XXXVII Cycle

RECONFIGURABLE PHOTONIC INTEGRATED PROCESSORS FOR FREE-SPACE COMMUNICATION AND COMPUTING

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Abstract:

Free-space optics offer multiple channels of communication and sensing for many applications. Similarly to the wavelength or polarization, the spatial degree of freedom of the light can be exploited to establish multiple parallel independent channels. Spatial division multiplexing has already been investigated, for instance, in optical fiber-based communications, to increase the link capacity and spectral efficiency; however, manipulation of spatially multiplexed free-space beams requires more complex approaches due to the presence of phenomena such as divergence and turbulence.

Integrated photonics is the technology for the generation, processing, and detection of light on a chip. This allows for dense integration of photonic integrated circuits (PICs) to implement complex functionalities in a large-volume and low-cost production. Silicon photonics, in particular, is widely considered the most promising platform due to the high refractive index contrast and its compatibility with the already existing semiconductor manufacturing technology.

In this thesis work, an approach based on PICs is adopted and experimentally demonstrated for arbitrary free-space beam manipulation in optical communication applications. In particular, the realized silicon PICs, designed to operate in the C-band, host multiple on-chip apertures connected to a multi-port interferometer consisting of tunable Mach-Zehnder interferometers that can self-configure to manipulate the free-space beams that are coupled into or out of the chip. PIC configuration is performed in situ via simple maximization or minimization algorithms on individual Mach-Zehnder interferometers, enabling accurate real-time control and scalability to large on-chip architectures.

The proposed technology is employed to implement a reconfigurable free-space optics receiver performing mode division demultiplexing on arbitrarily shaped, yet spatially overlapped, orthogonal free-space beams. The photonic chip was also used on the transmitter side to generate pairs of optimal orthogonal beams to be transmitted through an arbitrary linear optical system. In all cases, very low optical crosstalk (<-30 dB) is achieved between established channels, thus enabling parallel communication of signals modulated at several Gbps. Other architectures for the aperture array, such as a non-uniform array and for the multi-port interferometer, have also been investigated, and their use for different applications has been experimentally demonstrated.

The approach is scalable to accommodate more optical modes by integrating larger aperture arrays and multi-port interferometers, and it can be extended to multi-dimensional data transmission

schemes such as wavelength or polarization multiplexing. Other than applications in free-space optical communications, similar PIC architectures can be used in multi-mode sensing in fibers or free-space, or analog or quantum computing, as examples.

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