Dynamic Detector Selection for Multiple-Input Multiple-Output (MIMO) Multimode Fiber Links

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Abstract: We propose a dynamic greedy selection algorithm to reduce computational requirements in multimode MIMO fiber links employing a photodetector array. Simulations reveal that ∼90% of capacity is achievable from only a small subset of photodetectors.

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1. Introduction

Data rates in multimode fiber (MMF) links are known to be limited by modal dispersion [1]. Recently, it has been demonstrated that using multiple-input multiple-output (MIMO) signaling with signal processing allows the multiple modes of the fiber to be used efficiently, resulting in much improved data rates [2] that significantly exceed the rated bandwidth-length product by ∼15×. Moreover, further increases in performance are expected with increased number of transmitters and receivers, suggesting the use of compact laser and detector arrays as a scalable alternative to additional discrete components. With the recent advances in nanoscale lasers and detectors [3], such device arrays could prove practical in MIMO systems. However, such an approach would require a prohibitively large amount of computation to transmit and detect simultaneously using a large number of devices. In this paper, we consider for the first time a MMF-MIMO link employing laser and detector arrays and develop a dynamic detector selection technique that greatly reduces detection complexity by efficiently selecting only a subset of all the available detectors. Calculations indicate that 90% of maximum link capacity can be accessed using only 28% of all detectors, while requiring only ∼2% of the computation required if information from all detector elements is utilized for decoding.

2. System Model

We consider a MIMO-MMF optical link with an array consisting of one or more lasers at the transmitter and multiple detectors at the receiver butt coupled to a 1 km section of MMF, whose core diameter is 50 μm. For this system, using spectrally efficient modulation techniques, along with appropriate MIMO processing yields significant gains [4]; however, this would also require us to perform mathematical operations involving large ($N_D \times N_D$) matrices, which is prohibitively complex to perform at high data rates. In addition, it is known from wireless communication theory that detecting using the best few detection antennae (here photodetectors) can provide near capacity performance [5].

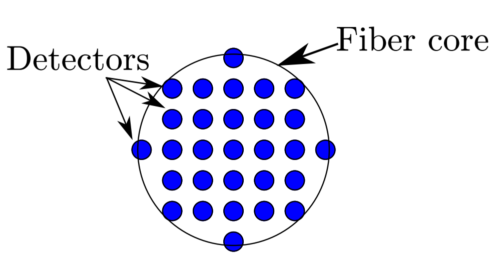


Fig. 1. Detector array pattern used for the simulations, overlayed upon a 50 μm fiber core. Photodetectors are 5 μm in diameter, separated by a pitch of 8 μm.

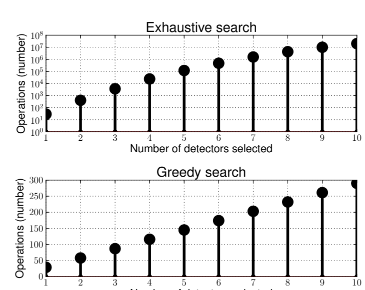
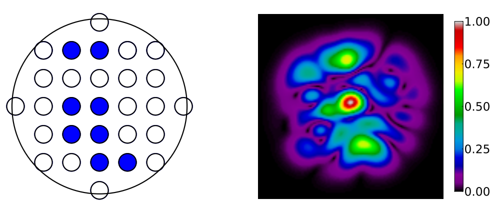


Fig. 2. Comparison of the number of arithmetic operations for exhaustive (log scale) vs. greedy search (linear scale).

Therefore, by selecting a smaller subset of n_D detectors for decoding the data at the receiver, the computational complexity would be greatly reduced, while not muchappreciably reducing the achievable data rate. As an example, a system consisting of 29 detectors, using all 29 detectors for detecting each megabit of data will require about $(29/8)^3 \approx 47\times$ more computation, as compared to using only the best eight detectors while still achieving 90% of the capacity. However, selecting these detectors for each channel state requires $\binom{N}{n_D}$ operations, which, again, is not tractable (for instance choosing the best 8 of 29 detectors needs $\binom{29}{8} \approx 4 \times 10^6$ operations). In the next section, we propose an effective detector selection method which performs fairly close to the optimal capacity.

3. Efficient Detector Selection

We begin with the fact that the capacity of an optical MIMO-MMF link satisfies the condition of *submodularity* with increasing number of active detectors [6]. Therefore, by choosing detectors one-by-one in such a way that each additional detector provides the maximum increase in capacity, called *greedy* selection algorithm, the achieved data rate can be at most constant factor away from the maximum capacity. Figure 2 compares the number of operations required for the exhaustive and greedy searches. In order to evaluate the performance of the greedy selection algorithm, we performed a simulation of a 1 km fiber link using a matrix model of the MMF [7], 29 lasers and detectors in the configuration shown in Figure 1, and compare optimal and greedy selection of detectors. Figure 3 shows one particular detector subset selection obtained by the greedy algorithm. Averaging over 700 channel realizations, we obtain Figure 4 and we make three observations: (1) selecting 8 detectors for each channel realizations obtains 90% of the capacity obtainable by using all 29 detectors; (2) the addition of detectors to the "active detector" subset provides diminishing returns; (3) the greedy detector selection achieves within 98% of the capacity that can be realized using the optimal subset of detectors obtained by an exhaustive search. For each channel realization, greedy selection of the best 8 detectors out of 29 requires about 250 comparisons, while processing every megabit of data requires about 2.1% of the computation cost with all 29 detectors. This saves about 98% in total computational cost over using all detectors.



(a) (b)

Fig. 3. (a) The optimal subset of detectors (shaded blue) obtained by the algorithm for (b) a particular output modal pattern.

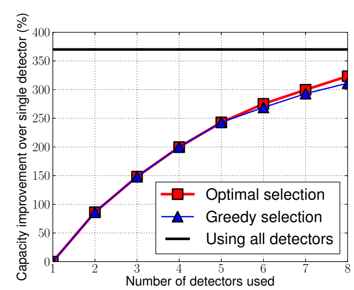


Fig. 4. Capacity improvement with selected detectors: optimal (exhaustive) selection vs. greedy selection

4. Conclusion

We have proposed an efficient means to select detectors for MIMO-MMF links using a greedy selection algorithm, which offers performance guarantees on achievable data rates while keeping complexity of implementation low. Simulations reveal that the selected detectors offer a performance close to the optimal capacity.

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