A Distributed Adaptive Signal Fusion Framework for Spatial Filtering within a Wireless Sensor Network

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***Abstract*—**The emergence of wireless sensor networks (WSNs) created the possibility to collect data and retrieve information in a way that was previously unfeasible or impractical. Fundamentally, WSNs consist of a multitude of spatially distributed sensor nodes which are able to locally process and communicate their measured data. Their usage has been adopted in a wide range of fields, such as health monitoring, acoustics and environmental studies among many others.

A specific task of interest is to find a filter which optimally fuses the signals over the network through a linear combination, i.e., spatial filtering. The filter is typically obtained as a result of an optimization problem involving the sensor signal statistics, e.g., a least squares problem or a (generalized) eigenvalue decomposition of the spatial covariance matrix of the sensor signals. Although a centralized setting – in which all the data acquired in the network is sent to a central node for processing – could be considered as a straightforward solution, it would create energy and communication bandwidth requirements which are too burdensome for many practical settings, implying the necessity of a fully distributed approach. Various algorithms have been proposed describing distributed approaches for signal processing, such as diffusion [1], incremental strategies [2] and consensus [3]. However, most of these existing methods for distributed signal processing make the assumption that the objective function f of the problem can be written as $\sum_k f_k$, where f_k only depends on the data of node k, which is not satisfied in various settings and especially in the case of spatial filtering. Instead, the common attribute between different spatial filtering problems is that the objective depends on the optimization variable X solely through the fusion/filtering expression $X^T\mathbf{y} = \sum_k X_k^T\mathbf{y}_k$, where $\mathbf{y}_k$ corresponds to the signal measured at node k, while X_k is the block of X filtering node k's signal. An illustrative example of the difference between the setting of our problems of interest and the one of existing distributed signal processing algorithms is given in Figure 1.

We propose the distributed adaptive signal fusion (DASF) algorithmic framework for signal fusion and spatial filtering problems in a distributed context. The main result is a generic iterative algorithm which reduces the energy and communication requirements in the WSN by only allowing the nodes of the network to communicate fused (and hence compressed) signals between each other. When spreading out the iterations over time (i.e., over different data batches), the algorithm becomes adaptive to small changes in the statistics of the observed signals and can therefore be used in tracking applications as well. We show that the algorithm converges to the optimal filter that corresponds to the solution of the centralized filter design problem. This generic algorithm covers a wide span of well-known spatial filter design principles as special cases, including principal component analysis (PCA), minimum variance beamforming, least squares regression, multi-channel Wiener filtering, canonical correlation analysis (CCA), generalized eigenvectors, trace ratio optimization, and more. The DASF framework covers several distributed algorithms for such problems such as for linearly constrained minimum variance beamforming [4] or PCA [5].

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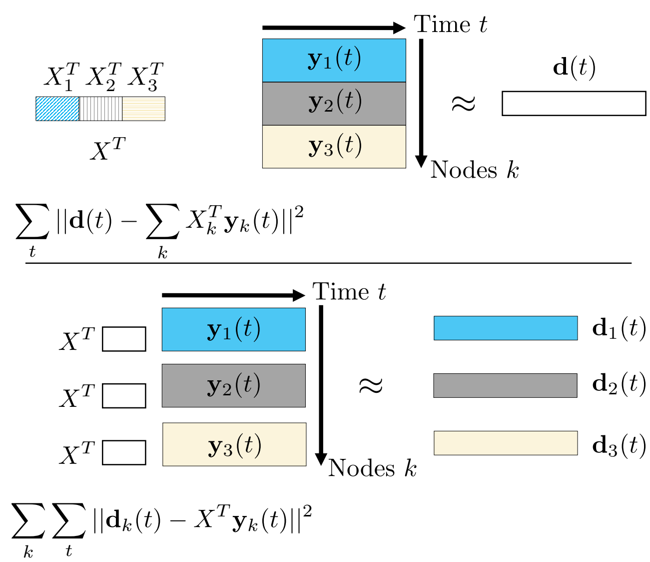

Fig. 1. Comparison of the DASF framework setting for a 3−node network (top) and the traditional consensus-type setting with separable objectives (bottom) with corresponding example objective functions for the case of least squares estimation.

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