

Compressive Topology Identification of Interconnected Dynamic Systems via Clustered Orthogonal Matching Pursuit

Bohan M. Samandaji, Tyrone L. Vincent, and Michael B. Wakin

Abstract—In this paper, we consider topology identification of large-scale interconnected dynamical systems. The system topology under study has the structure of a directed graph. Each edge of the directed network graph represents a Finite Impulse Response (FIR) filter with a possible transport delay. Each node is a summer, whose inputs are the signals from the incoming edges, while the output of the summer is sent to outgoing edges. Edges of the graph can be of different unknown orders and delays. Both the graph topology and the FIR filters and delays that make up the edges are unknown. We aim to do the topology identification from the *smallest possible number* of node observations when there is limited data available and for this reason, we call this problem Compressive Topology Identification (CTI).

Inspired by Compressive Sensing (CS) which is a recent paradigm in signal processing for sparse signal recovery, we show that in cases where network interconnections are suitably sparse (i.e., the network contains sufficiently few links), it is possible to perfectly identify the network topology along with the filter orders and delays from small numbers of node observations, even though this leaves an apparently ill-conditioned identification problem.

The main technical novelty of our approach is in casting the identification problem as the recovery of a *clustered-sparse* signal $\mathbf{z} \in \mathbb{R}^N$ from the measurements $\mathbf{b} = \mathbf{A}\mathbf{z} \in \mathbb{R}^M$ with $M \ll N$, where the measurement matrix \mathbf{A} is a block-concatenation of Toeplitz matrices. To this end, we introduce a greedy algorithm called Clustered Orthogonal Matching Pursuit (COMMP) that tackles the problem of recovering clustered-sparse signals from few measurements. In a clustered-sparse model, in contrast to block-sparse models, there is no prior knowledge of the locations or the sizes of the clusters. We discuss the COMMP algorithm and support our discussions with simulations.

I. INTRODUCTION

Systems that have a large number of inputs and outputs present a particular challenge for system identification. An important choice for the system identification practitioner is that of proper model structure — if the correct model structure can be chosen, then the parameters can be identified from data consistently. However, if the incorrect model structure is chosen, the estimates can have excessive bias or variance. In this paper, we focus on systems with a large number of observable variables, where the relationships between these variables can be described by a signal flow graph with nodes of low maximum degree. Examples of such systems come when modeling building thermal dynamics [1], [2], biological systems [3], and economics [4]. The model structure is specified by the connections that occur in the

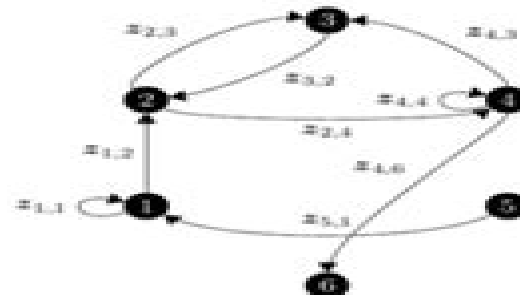


Fig. 1. Network model of 6 interconnected nodes. Each edge of the directed network graph $(\mathbf{A}_{i,j,k})$ represents an FIR filter with possible transport delay. Each node is a summer, whose inputs are the signals from the incoming edges, while the output of the summer is sent to outgoing edges. Edges of the graph can be of different unknown orders and delays.

graph, but with a large number of signals, there are a large number of potential connections, only a small number of which will be present. Thus, in order to proceed with system identification, there is a need for effective “topological identification” procedures [5]–[8] which, given measurements of the nodes of an interconnected dynamical system over a finite time interval, determine the correct interconnection topology.

One solution for the topology identification problem comes from Materassi and Innocenti [7] in the case that the interconnection graph has a tree structure and enough data is available to form reliable estimates of cross-power spectral densities. In this paper, we consider a more general setting, allowing arbitrary interconnections (including trees, loops, and self-loops) between nodes in the network, but we assume that the interconnection graph is sparse in the sense that each node has a relatively low in-degree. Fig. 1 shows one such example network. However, we also assume that each node contains a measurable exogenous input signal, while in [7] the input is an unmeasured random process. We also focus on the case of a small number of measurements, indeed, so small that the parameter estimation problem would not be invertible if connections to all nodes were postulated.

In this paper, the identification problem is formulated as the recovery of a *clustered-sparse* signal $\mathbf{z} \in \mathbb{R}^N$ from the measurements $\mathbf{b} = \mathbf{A}\mathbf{z} \in \mathbb{R}^M$, where the measurement matrix \mathbf{A} is a block-concatenation of Toeplitz matrices. A signal $\mathbf{z} \in \mathbb{R}^N$ is clustered-sparse when it only has K non-

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