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Data-Driven Distributed Predictive Control via Network Optimization

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Abstract

We address the problem of using data to control a network system without a system model or any intermediate parameter identification. We consider a network system whose dynamics is described by a linear system defined by unknown matrices. The dynamics of each node are coupled with those of its neighbors and nodes may only communicate with their neighbors. Each node wants to drive its own state to the origin while minimizing a quadratic function of its inputs and states. The goal for collective system can be formulated as a Linear Quadratic Regulation (LQR) problem on the network system. Solving this problem in a distributed way is nontrivial since the agents' decision on its control inputs are coupled through the dynamics. Since system matrices are unknown, each agent relies on data, specifically it has access to its own state and input, as well as the states of its neighbors, in a single input-state trajectory of the system.

Our work extends the DeePC framework developed by (Coulson et al., 2019) to network systems where each node only has partial access to the data. The so-called *fundamental lemma* (Willems et al., 2005), a result from Behavioral Systems Theory, gives a characterization of all possible system trajectories from a single sample trajectory when the input is sufficiently exciting. Using this result, we introduce a distributed, data-based representation of the system, with which agents can cooperate to predict future trajectories when the input data is persistently exciting of sufficiently high order. Our study gives conditions on the input sequence guaranteeing that the data-based representation can characterize all possible trajectories of the system, but the conditions are difficult to check in a distributed manner. This motivates our study of sufficient conditions for identifiability that can be checked in a distributed manner with the information available to each agent.

We employ the data-based representation to pose an equivalent network optimization problem that can be solved with the data locally available to each agent, and is amenable to a variety of distributed optimization algorithms. We implement a controller by solving this problem in a receding horizon manner. Because the flow must be terminated in finite time, the optimization problem can only be solved approximately by any asymptotically convergent distributed algorithm. Our analysis shows that the introduced control scheme is still stabilizing for the network system provided that the approximate solution is sufficiently close to the true optimizer. We have validated the performance of the proposed data-based controller through numerical experiments on a star graph with 5 nodes and a Barabási-Albert graph with 10 nodes. In both cases, the controller stabilizes the system to the origin, and its performance is almost identical to that of the model-based LQR controller.

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