Appointed-time bipartite synchronization of multi-agent systems over switching networks

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***Abstract*—Achieving synchronization in multiagent systems (MAS) over switching networks presents a unique challenge, especially when the synchronization needs to occur within a predetermined or appointed time. This paper addresses the problem of appointed-time bipartite synchronization in MAS, where agents are required to synchronize with a sign-inverted agreement over a switching network. Unlike conventional synchronization, bipartite synchronization demands that agents in a network align their states with opposite signs, which is particularly useful in scenarios like formation control and consensus in cooperative-competitive networks. The proposed control strategy leverages the theory of nonsmooth analysis and Lyapunov functions to ensure that synchronization is achieved within a fixed appointed time, irrespective of the switching topologies and possible disturbances. The effectiveness of the method is demonstrated through rigorous theoretical analysis and simulation results, highlighting its potential in various practical applications where timely and structured synchronization is critical.**

***Index Terms*—Multi-agent systems, appointed-time, bipartite consensus, switching networks.**

I. Introduction

The study of synchronization in multiagent systems (MAS) has become a significant area of research, driven by the need to coordinate the actions of distributed agents in a variety of applications, including robotics, sensor networks, distributed computing, and autonomous vehicles. Synchronization in MAS refers to the process by which agents, through local interactions, align their states over time to achieve a common behavior or objective. This could involve matching velocities in a group of autonomous vehicles, aligning phases in a network of oscillators, or reaching a consensus in decision-making systems.

Traditional synchronization problems in MAS typically involve all agents converging to a common state or trajectory. However, in many practical scenarios, a more complex form of synchronization, known as bipartite synchronization, is required. Bipartite synchronization occurs when agents in a network synchronize their states with opposite signs. This means that for a given pair of agents, one agent's state is the negative of the other's at the point of synchronization. Such a scenario is common in systems where agents are divided into two groups with opposing objectives or roles, such as in cooperative-competitive networks, formation control, and certain types of consensus problems.

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1. Bipartite Synchronization in Multiagent Systems

Bipartite synchronization is a generalization of the consensus problem, where instead of all agents reaching the same state, agents are required to reach a state that is either identical or sign-inverted with respect to their neighbors. This type of synchronization is particularly relevant in signed networks, where the edges between agents are assigned either a positive or negative weight. Positive weights indicate cooperation, while negative weights indicate competition or antagonism.

The mathematical modeling of bipartite synchronization involves the use of signed graphs, where the agents are represented as nodes and the interactions between them as edges with associated signs. The challenge in achieving bipartite synchronization lies in ensuring that all agents in the network, despite the sign of their interactions, converge to the desired state configuration. This requires the design of control laws that account for the sign structure of the network and ensure that the agents' states evolve according to the desired bipartite pattern.

2. Switching Networks and Their Challenges

The complexity of achieving bipartite synchronization increases when the underlying network topology is not static but switches over time. Switching networks are networks where the connections between agents (i.e., the edges of the graph) can change over time, either due to environmental factors, agent mobility, or other dynamic processes. In such scenarios, the challenge is not only to achieve synchronization but to do so consistently despite the changing network topology.

Switching networks pose several challenges for synchronization. First, the changing connectivity can disrupt the information flow between agents, making it difficult to maintain the desired synchronization pattern. Second, the variability in network structure may introduce delays or lead to temporary disconnections, which can further complicate the synchronization process. Lastly, ensuring that synchronization occurs within a fixed, appointed time adds an additional layer of complexity, as the control strategy must be robust enough to handle the variability in network topology while still guaranteeing timely convergence.

3. Appointed-Time Synchronization

Appointed-time synchronization refers to the scenario where synchronization is required to be achieved within a predetermined, fixed time, regardless of the initial conditions or the dynamic nature of the network. This is in contrast to asymptotic synchronization, where the convergence time is not fixed and can vary depending on system parameters and initial conditions.

The concept of appointed-time control is particularly important in applications where timing is critical, such as in time-sensitive communication networks, coordinated attacks in military operations, or synchronized actions in robotics. In these scenarios, it is not sufficient for the agents to merely synchronize; they must do so within a strict timeframe to ensure the success of the overall operation.

Achieving appointed-time bipartite synchronization in switching networks is a challenging task that requires a careful balance between the speed of convergence and the robustness of the control strategy. The control law must be designed to enforce rapid convergence to the desired synchronization state while being resilient to changes in the network topology and potential disturbances.