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Event-triggered leader-following consensus for multi-agent systems with semi-Markov switching topologies

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ABSTRACT

This paper investigates the event-triggered leader-following consensus problem for a multi-agent system with semi-Markov switching topologies. A sampled-data-based event-triggered transmission scheme is introduced to reduce unnecessary communication. By modeling the switching of network topologies by a semi-Markov process and adopting an event-triggered transmission scheme, a new consensus protocol is proposed. Compared with the traditional Markovian switching topologies, the transition rates in the semi-Markov switching topologies are time-varying, which is more general and practicable. Through utilization of an appropriate Lyapunov–Krasovskii functional, some sufficient conditions are derived, which guarantee that the leader-following consensus can be achieved in mean-square sense. Moreover, the consensus gain matrices and parameter of the event-triggered scheme can be efficiently solved out. Finally, a numerical example illustrates the effectiveness of the proposed design technique.

1. Introduction

In recent years, distributed coordinated control of multi-agent systems has been studied extensively due to its broad applications in cooperative control of unmanned airborne vehicles [1], automated highway systems [2], distributed sensor networks [32], etc. As an important issue in distributed coordinated control of multi-agent systems, consensus problem has received considerable attention [9,21,26–29,35,36], whose objective is to design a distributed consensus protocol such that the states of all agents converge to an agreement state by using only local information exchange. Specifically, when the agreement state is provided by a leader agent, the leader-following consensus problem arises [11,26,28]. In leader-following multi-agent systems, the leader is usually independent of the followers but has influence on the followers behaviors [14,15]. Thus, the objective of controlling a group of agents can be realized by controlling only the leader, which greatly simplifies the analysis and design of multi-agent systems and helps to save energy and reduce control costs [22].

On the other hand, the event-triggered control strategy is an effective way to save communication and computation resources. Compared with a time-triggered strategy, data transmission and control updates in the event-triggered strategy are determined by an event-triggered condition. If the event condition is violated, which means that the measurement error

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exceeds a threshold, control updates should be transmitted [39,40]. Hence, the event-triggered strategy can reduce unnecessary communication and computation resources [37]. For a multi-agent system, in order to reduce unnecessary communication, each agent is often equipped with an event-triggered processor, which decides whether or not data of agent should be broadcasted to the other agents. Up to date, many works on the event-triggered consensus have been reported [6,13,24,31]. In [6], a decentralized event-triggered strategy has been proposed to decrease the number of the control updates, however, all agents need to monitor their neighbors' states continuously. Such continuous detection does not reduce over-consumption of communication. In order to overcome this limitation, some new event-triggered consensus algorithms with sampled-data event detection have been provided in [13,24], where event-triggered condition is only required to be measured at sampling instants. In [43], the event-based consensus of general linear multi-agent systems has been considered. An improved algorithm is proposed for determining event time sequences, which can reduce not only control updates, but also communication between neighboring agents. For more details on event-triggered control and consensus problems, we refer the reader to some recent survey papers [7,10,12].

Most of the above works focus on the multi-agent systems with fixed topology. However, in practical systems, the communication topology among agents may change over time, due to unknown abrupt phenomena such as sudden environmental changes, random failures and repairs of components. For the sake of describing this kind of time-varying topology, a simple method is that the time-varying topology is modeled as Markov switching topologies. So far, many works regarding multi-agent systems with Markov switching topologies have been reported in the literature; see, e.g., [9,23,25,34,41] and the references therein. However, the time-varying topology described by the Markov process has many limitations in applications, since the jump time of a Markov chain is, in general, exponentially distributed. Hence, the results on Markov switching topologies are conservative in some senses [19,20]. Very recently, some researchers have devoted their efforts to semi-Markov jump topologies [18,33]. Compared with conventional Markov switching topologies, the probability distribution of sojourn-time in semi-Markov switching topologies is relaxed from exponential distribution to a more general probability distribution, such as Weibull distribution, Gaussian distribution, etc. Hence, the semi-Markov switching topologies are more general than the conventional Markov switching topologies due to their relaxed conditions on the probability distributions. However, there are few results on the leader-following consensus of multi-agent systems with semi-Markov switching topologies [5].

Motivated by the above discussion, this paper addresses the event-triggered consensus of leader-following multi-agent systems with semi-Markov switching topologies, where each agent has general linear dynamics. The main contributions are summarized as follows. (1) Compared with the existing results on event-triggered leader-following consensus, a new consensus protocol based on the sampled-data and semi-Markov switching topologies is proposed for leader-following multi-agent systems. (2) A sampled-data-based event-triggered transmission scheme is designed. The event-triggered condition is only required to be measured and calculated at sampling instants. (3) The Laplacian matrices of switching topologies are not required to be symmetric. This work is a natural continuation of our recent work [4] on second-order multi-agent systems without leader and semi-Markov switching topologies.

The following notations will be used throughout this paper, R^n represents the n dimensional Euclidean space. I_n denotes an $n \times n$ identity matrix, 0 denotes zero matrix with an appropriate dimension. $diag\{\dots\}$ stands for a diagonal matrix. $P > 0$ ($P \geq 0$) means that P is symmetric and positive definite (semi-definite). The superscript "T" denotes matrix transposition and the asterisk "*" in a matrix is used to represent the term that is induced by symmetry. $\otimes$ represents the Kronecker product. $\mathbb{E}\{\cdot\}$ stands for the mathematical exception operator. $\|x\|$ refers to the Euclidean norm of vector x. We use $col\{x_1, x_2, \dots, x_m\}$ to denote the column vector $\left[x_1^T, x_2^T, \dots, x_m^T\right]^T$.

2. Preliminaries and problem formulation

2.1. Graph theory

In this paper, we use a directed graph $\overline{\mathcal{G}}$ to describe the information exchange among N followers and a leader labeled by v_0, where $\overline{\mathcal{G}}$ consists of graph $\mathcal{G}$, leader node v_0 and directed edges from leader v_0 to followers. $\mathcal{G} = (\mathcal{V}, \mathcal{E}, \mathcal{A})$ denotes a directed graph among the N followers, where $\mathcal{V} = \{v_1, v_2, \dots, v_N\}$ is the set of N followers, $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$ is the set of directed edges, and $\mathcal{A} = \left(a_{ij}\right)_{N\times N}$ is a weighted adjacency matrix. A directed edge ϵ_{ij}in $\mathcal{G}$ is the ordered pair of nodes (v_i, v_j), where node v_i can receive information from node v_j. In this case, node v_j is a neighbor of node v_i and the neighbor index set of node v_i is denoted by $N_i = \left\{j | \left(v_i, v_j\right) \in \mathcal{E}\right\}$. If $\epsilon_{ij} \in \mathcal{E}$, then $a_{ij} > 0$, otherwise $a_{ij} = 0$. Furthermore, we assume that $a_{ii} = 0$ for all i. The Laplacian matrix of the directed graph $\mathcal{G}$ is defined as $L = \left(l_{ij}\right)_{N\times N}$ with $l_{ii} = \sum_{j\in N_i} a_{ij}$ and $l_{ij} = -a_{ij}$, for $i \neq j$. A directed path in $\mathcal{G}$ from node v_j to v_i is a sequence of directed edge of the form $\left(v_i, v_{i_1}\right)$, $\left(v_{i_1}, v_{i_2}\right)$, $\dots$, $\left(v_{i_l}, v_j\right)$ with distinct nodes v_{i_k}, $k = 1, 2, \dots, l$. A directed graph is said to contain a directed spanning tree if there exists at least one node having a directed path to all other nodes. We assume that the leader does not receive any information from the followers, and the leader is a neighbor of only a part of the followers. A diagonal matrix $\mathcal{B} = diag\{b_1, b_2, \dots, b_N\}$ is the leader adjacency matrix associated with $\overline{\mathcal{G}}$, where $b_i > 0$ if node v_0 is a neighbor of node v_i and $b_i = 0$ otherwise.

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