Information Sciences 373 (2016) 110–123

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Event-driven multi-consensus of multi-agent networks with repulsive links☆

Bin Hu[a], Zhi-Hong Guan[a,*], Xiao-Wei Jiang[a], Ming Chi[a], Rui-Quan Liao[b], Chao-Yang Chen[a]

[a] College of Automation, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Petroleum Engineering College, Yangtze University, Jingzhou 434023, China

ARTICLE INFO

Article history:
Received 1 December 2015
Revised 24 August 2016
Accepted 26 August 2016
Available online 31 August 2016

Keywords:
Clustering
Multi-agent networks
Multi-consensus
Event-driven control
Repulsion

ABSTRACT

This paper studies multiple coordination of multi-agent networks under an event-driven paradigm. For an undirected connected graph, a node clustering scheme is first adopted to ensure a relatively strong degree of connectivity within each potential subgroup, and some repulsive effect is used to deal with the extra-subgroup links. To reduce unnecessary communication, a distributed event-driven controller is designed via coupled intra-subgroup and extra-subgroup information. Based on the LaSalle's invariance principle, it is shown that under the proposed event-driven control configuration, multi-agent networks can realize multi-consensus without any balanced requirement on the underlying topologies. Simulation work is presented to validate the theoretical results.

1. Introduction

Distributed cooperation over MANs (multi-agent networks) has successfully developed into an advanced research field due to its broad application in control and communication engineering [34,26,12,11,20,28,16]. Composed of multiple autonomous agents, MANs usually display various emergent behaviors [16,25,29,21], among which consensus is one fundamental collective behavior. In recent years, consensus has been widely exploited to describe information propagation and opinion dynamics in SNs (social networks) [34,20,17], to demonstrate dynamics evolution of robots or UAVs (unmanned aerial vehicles) tracking target in battlefield [26,28,10,14], or to promote distributed filtering/computation on WSNs (wireless sensor networks) [8,36,32,33].

Due to diversification in the environment, a group of agents may have several emergent behaviors. For examples, social members may have distinct opinions on one topic [17,20], birds take several directions toward food sites [25,35], robots seek multitask diffusion [5,24], or a GN (genetic networks) possesses multistability [7,30]. Since consensus means that states of agents reach an agreement at one common value, it cannot be directly applied to the aforementioned multi-objective cases [6,11,12,19,22,26,34]. This situation motivates our current study of multi-consensus. In the paper, multi-consensus means that a group of agents reach multiple distinct agreements with respect to different subgroups in a dynamic way, which is akin to a generic version of group/cluster consensus [4,14,15,27,35].

☆ This work was partially supported by the National Natural Science Foundation of China under Grants 61473128, 61672245, 61472122, 61572208 and 61572084, and the Postdoctoral Science Foundation of China under Grant 2015M582224.

* Corresponding author.
E-mail address: zhguan@mail.hust.edu.cn (Z.-H. Guan).

http://dx.doi.org/10.1016/j.ins.2016.08.079

Little effort to date has been devoted on the issue of multiple coordination regarding MANs under general undirected topologies. Some relevant works nonetheless are done on group/cluster consensus [1,4,15,18,27,35]. These group/cluster consensus results in [27,35] rely on the assumptions of the underlying topologies, while Cassandras (2014) [4] has introduced a permutation into the adjacency matrix for graph partitions. Closely related to our work is bipartite consensus that has been analyzed in [1,18]. In contrast with the existing literature, we adopt undirected network topologies with time-varying $0-1$ couplings. In this context, the main difficulty of multiple coordination is how to choose a desirable collaborative interaction scheme, beyond the network dynamics. Specifically, how to select node members for each subgroup and how to deal with the intra-subgroup and extra-subgroup couplings are crucial problems.

To fix these problems, we introduce a kind of cooperative clustering scheme to handle the structure dynamics of networks, like the positive-cluster partition or community partition methods [9,17,21,23,24,29]. Furthermore, we exploit certain repulsion mechanism to reassign the extra-subgroup links from different subgroups. In fact, many related works, see, e.g., [1,18,35], resort to the negative coupling as a repulsive effect. It has been revealed that there are many other factors promoting repulsion or competition effects, such as the quorum sensing for multistability [2,7,30], or the edge betweenness issue for community [9,24]. Motivated by the above, we adopt the notion of repulsive links regarding the structure dynamics of networks. This repulsion approach would be helpful since there is no need of requiring a balanced network topology in pursuit of multiple coordination.

On the other hand, event-driven control has drawn much research interest for its advantages of communication reduction and control energy saving in distributed systems [3,6,8,13,22,32,33,36,37]. The distinct feature of event-driven control is that the plant is only supposed to update when some state-based event occurs, such as a logic condition is violated or network topology switches, not by the clock. Early work studied the consensus problem by a continuous-time event-triggered method [6,36,37]. Ge and Han (2015) [8] solved the H_∞ filtering over WSNs with communication delays by a distributed event-triggered strategy. Making use of sampling control, the hybrid event-driven method with sampled data has also received much attention. Meng and Chen (2013) [22] applied sampled data to establish an event-based consensus algorithm. [13] studied sampled-data consensus using distributed event-triggered transmission strategy. Wen et al (2015) [32] proposed a hybrid event-time-triggered transmission and control strategy for stabilization of networked control systems. Naturally, one question arises: can the event-driven control method promote multiple coordination of MANs?

The major contribution of this paper is to provide an event-driven strategy for multiple coordination of MANs with generic undirected topologies. Different from the existing literature [1,4,15,18,27,35], we first adopt a cooperative clustering scheme, which helps guaranteeing a relatively strong degree of connectivity for each potential subgroup. Furthermore, based on the sampling-event scheme [8,22,32,33], we exploit an improved event-driven control approach. The triggering condition under consideration is developed with sampled data, and is composed of coupled intra-subgroup and extra-subgroup information. The distributed controller is improved in the sense that the inter-event time of each agent can be adjusted by the coupling strength between distinct subgroups. Besides, to accommodate multi-consensus, we abandon balanced requirements on the network topologies [9,10,14,25], but resort to some event-driven repulsion mechanism. With the aid of LaSalle's invariance principle, we prove that with proper event-driven conditions, the developed repulsion mechanism can contribute to multi-consensus. These results suggest that taking into account the structure dynamics of networks, no further requirement of connectivity is needed while pursuing multiple coordination.

The outline of the paper is as follows. Section 2 formulates the multi-consensus problem under investigation and gives some preliminaries. Section 3 presents the design procedures of some event-driven control and repulsion schemes, and carries out a multi-consensus criterion. Section 4 gives two numerical examples. Section 5 concludes the paper.

2. Problem formulation and preliminaries

Consider a network of n ($n \geq 4$) agents, the network topology is an undirected graph $G = \{V, E\}$, where $V = \{1, 2, \ldots, n\}$ and $E = \{(i, j) | i, j \in V\}$ are respectively the vertex and edge sets. The time-varying matrix $A(t) = [a_{ij}(t)]_{n\times n}$ represents the adjacency matrix at time $t \geq 0$. For simplicity, we assume that $A(t)$ is a $0-1$ matrix, i.e., $a_{ij}(t) = 0$ for all $i = j$, $a_{ij}(t) = 1$ if the link $(i, j) \in E$ is active at time t, otherwise $a_{ij}(t) = 0$. $N_i(t) = \{j | j \in V, a_{ij}(t) = 1\}$ denotes the neighboring set of agent i at time t.

Each agent is modeled by

$$\dot{x}_i(t) = u_i(t), \quad t \geq 0, \quad i \in V, \tag{1}$$

where $x_i(t) \in \Re$ is the state of agent i at time t, $u_i(t) \in \Re$ represents a control updating rule, usually in a distributed pattern.

Similar to [1,4,15,18,27,35], MAN (1) is said to contain m ($m \geq 2$) subgroups, $\{V_r\}_{r=1}^m$ ($|V_r| \geq 2$), if

$$\cup_{r=1}^m V_r = V, \quad V_r \cap V_q = \emptyset \quad (r \neq q).$$

Definition 1 (Multi-consensus)**.** Consider MAN (1) with an initial network topology $G = \{V, E, A(0)\}$. If there exist m subgroups $\{V_r\}_{r=1}^m$ such that for any initial state $\{x_1(0), x_2(0), \ldots, x_n(0)\}$,

$$\lim_{t\to\infty} \left| x_i(t) - x_j(t) \right| = 0, \quad \forall i, j \in V_r, \quad r = 1, \ldots, m,$$

then MAN (1) is said to reach multi-consensus asymptotically.