Letter

Finite-Time Synchronization of Complex Networks With Intermittent Couplings and Neutral-Type Delays

Engang Tian, Yi Zou, and Hongtian Chen

Dear Editor,

This letter focuses on the finite-time synchronization (FTS) of neutral-type complex networks with intermittent couplings. Different from most of the existing references concerning neutral-type systems, a delay-independent dynamical event-triggering controller is considered, operating the same way as the intermittent coupling and excluding the Zeno behavior naturally. By introducing a vector-based Lyapunov-Krasovskii functional (LKF), the FTS criteria are obtained based on a set of vector inequalities, which are less conservative than the corresponding algebraic one. Finally, a simulation example is given to illustrate the merits of the theoretical analysis.

Recently, an increasing interest could be found in the synchronization problem of complex networks (CNs) with intermittent couplings. For example, Hu *et al*. [1] considered the asymptotic synchronization of complex-valued dynamic networks with intermittent couplings. Wen *et al*. [2], [3] studied the consensus of linear multi-agent systems with intermittent communication. However, some assumptions are used to support these research, including the periodic coupling and decoupling intervals [2], [3], or a large width of coupling intervals [1], which are not conducive to the practical applications of intermittently coupled networks. Hence, it motivates us to find a new relationship between the coupling and decoupling widths to shrink the operation range of the coupling.

On the other research front, the finite-time synchronization and control of CNs with time delays is a long-time research topic. While, as reported in [4], it is hard to eliminate the effects caused by time delays in the finite-time control area. Recently, the FTS of neural networks with hybrid delays has been achieved by presenting 1-norm analysis techniques in [5]. Along with this line, FTS of CNs with various types of delays has been investigated [6], [7]. However, there is few research on FTS of neutral-type CNs (NTCNs), where the delays occur in the derivatives of the system state. Although He *et al*. [8], [9] attempted to study the FTS of neutral-type systems, those controllers are very complex and contain both state and derivatives delays, which are difficult to be applied in practice. It necessitates the design of a simple controller without any delayed information to achieve FTS of NTCNs with intermittent couplings.

More recently, an event-triggering scheme (ETS) has stirred much attention from scholars since it can reduce the unnecessary data transmission [10]–[12]. By introducing an internal dynamic variable, the dynamic event-triggering scheme (DETS) is presented in [13]. Since then, a multitude of studies on DETS have been published [14], [15]. Although [16] considered the DETS-based finite-time control for switched systems, this method can not be extended to delayed systems, also not mentioning the more complex NTCNs. Therefore, this letter is devoted to design a simple delay-free controller with DETS to guarantee the FTS of NTCNs with intermittent couplings.

Corresponding author: Hongtian Chen.

Citation: E. G. Tian, Y. Zou, and H. T. Chen, "FTS of CNS with intermittent couplings and neutral-type delays," *IEEE/CAA J. Autom. Sinica*, vol. 10, no. 10, pp. 2026–2028, Oct. 2023.

E. G. Tian and Y. Zou are with the School of Optical-Electrical and Computer Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China (e-mail: tianengang@163.com; yizoumath@126.com).

H. T. Chen is with the Department of Automation, Shanghai Jiao Tong University, Shanghai 200240, China (e-mail: hongtian.chen@sjtu.edu.cn).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/JAS.2023.123171

To sum up, the main contributions of this letter are summarized as: 1) An array of neutral-type nonlinear systems with intermittent couplings are considered, where the restrictions on coupling and decoupling intervals are more general than those in [1]–[3]. Moreover, the controllers are active in the same way as the coupling interval, which is different from the existing controlled models. 2) To realize the FTS of NTCNs, a simple controller is designed. Different from [8], [9], the developed controller is delay-independent, which is more practical since the time-varying delay is not available in many cases. 3) The DETS is introduced in the controller. Specifically, the established DETS contains three parameters, which can exclude Zeno phenomenon automatically and adjust the triggering intervals as well as the convergence rate flexibly. 4) Novel vector-based LKFs are designed by introducing some free vectors, and sufficient conditions formulated by vector inequalities are proposed to guarantee the FTS of NTCNs, which are less conservative than the algebraic inequality results [5].

Notation: I_n is the n-dimension identity matrix; $\mathbf{0}_n(\mathbf{1}_n)$ means all entries of the column vector are 0 (1); $C\in([-\tau,0],\mathbb{R}^n)$ denotes the set of continuous functions from $[-\tau,0]$ to $\mathbb{R}^n$; $\mathbf{v}>0$ ($\mathbf{v}<0$) implies all the entries of $\mathbf{v}$ are positive (negative); $\mathbb{N}_a=\{0,1,\dots,a\}$.

Problem statement: Considered the following neutral-type system:

$$\dot{x}(t)=Q(x(t)) \tag{1}$$

where $Q(x(t)) = E\dot{x}(t-\tau_1(t))+Ax(t)+Bf(x(t))+Ch(x(t-\tau_2(t)))$, $x(t)=(x_1(t),x_2(t),\dots,x_n(t))^T\in\mathbb{R}^n$ is the state variable of (1), $A=(a_{ij})$, $B=(b_{ij})$, $C=(c_{ij})$ and $E=(\tilde{e}_{ij})\in\mathbb{R}^{n\times n}$ are connection matrices; $f(\cdot)$ and $h(\cdot)$: $\mathbb{R}^n\to\mathbb{R}^n$ represent the continuously nonlinear vector-valued functions, and satisfies $|f_i(\hbar)-f_i(\tilde{\hbar})|\le\sum_{j=1}^n l_{ij}^f|\hbar_j-\tilde{\hbar}_j|$, $|h_i(\hbar)-h_i(\tilde{\hbar})|\le\sum_{j=1}^n l_{ij}^h|\hbar_j-\tilde{\hbar}_j|$ for $\hbar,\tilde{\hbar}\in\mathbb{R}^n$, where $l_{ij}^f>0$ and $l_{ij}^h>0$ are constants. $\tau_1(t)$ and $\tau_2(t)$ are time-varying delays satisfying $0\le\tau_\iota(t)\le\tau_\iota$ and $\dot{\tau}_\iota(t)\le\mu_\iota<1$, respectively, with τ_ι and μ_ι ($\iota=1,2$) being known constants. The initial condition of (1) is given by $\phi(s)\in C([-\tau_{\max},0],\mathbb{R}^n)$, where $\tau_{\max}=\max\{\tau_1,\tau_2\}$.

Consider an intermittently coupled systems with N nodes of (1)

$$\dot{y}_i(t)=Q(y_i(t))+\sigma(t)\Big[\sum_{j=1}^N g_{ij}\Phi y_j(t)+U_i(t)\Big],\ \ i\in\mathbb{N}_N \tag{2}$$

where $y_i(t)=(y_{i1}(t),y_{i2}(t),\dots,y_{in}(t))^T\in\mathbb{R}^n$ denotes the state of the ith node; $\Phi=\mathrm{diag}(\phi_1,\phi_2,\dots,\phi_n)$ is the inner coupling matrix, and $G=(g_{ij})_{N\times N}$ is the outer coupling matrix satisfying diffusion condition. $\sigma(t)=1$, when $t\in[t_{2k},t_{2k+1})$, otherwise $\sigma(t)=0$, where the time sequence $\{t_k\}_{k\in\mathbb{N}}$ is a strictly increasing sequence and satisfies $t_0=0$, $\lim_{k\to+\infty}t_k=+\infty$. Specially, $[t_{2k},t_{2k+1})$ and $[t_{2k+1},t_{2k+2})$ are the so-called coupling and decoupling interval, respectively. $U_i(t)$ is the control input to be designed later. The initial value of (2) is described as $\psi_i(s)\in C([-\tau_{\max},0],\mathbb{R}^n)$.

Remark 1: This intermittently coupled model can be utilized to describe the phenomenon that communication obstacles occur intermittently [1]–[3] or an artificial communication strategy to avoid unnecessary transmission. In addition, it is assumed that the controller $U_i(t)$ is active only when there are information changes between nodes, which also can be regarded as the intermittent control scheme.

To achieve the FTS shown in [5], following event-triggered controller (ETC) is adopted as:

$$U_i(t) = -R_i e_i(t^{\rho}_{i,2k}) - \zeta \text{sign}(e_i(t^{\rho}_{i,2k}))$$
$$t \in \mathcal{T}^{\rho}_{i,2k} = [t^{\rho}_{i,2k}, t^{\rho+1}_{i,2k}) \cap [t_{2k}, t_{2k+1}),\ \ k \in \mathbb{N} \tag{3}$$

where $i \in \mathbb{N}_N$, $R_i = \text{diag}(r_{i1}, r_{i2}, \ldots, r_{in})$ is the control gain matrix, $\zeta > 0$ is a tunable constant, sign$(\cdot)$ is the sign function. $t^0_{i,2k} = t_{2k}$, $t^{\rho}_{i,2k}$ means the ρth event-triggering instant of the ith node on the interval $[t_{2k}, t_{2k+1})$, which is determined by

$$t^{\rho+1}_{i,2k} = \inf\{t > t^{\rho}_{i,2k} | \ \mathbf{u}^T_i |\tilde{e}_i(t)| - \sigma \mathbf{u}^T_i |e_i(t)| > \theta \delta^{-\kappa t}\} \tag{4}$$

where $\tilde{e}_i(t) = -R_i e_i(t) - \zeta \text{sign}(e_i(t)) - U_i(t)$, $0 < \mathbf{u}_i \in \mathbb{R}^n$, $\sigma > 0$, $\theta > 0$, $\delta > 1$ and $\kappa > 0$ are given tunable constants.

Remark 2: Because of $\theta\delta^{-\kappa t} > 0$, the triggered condition (4) can automatically avoid the Zeno behavior. Moreover, due to the introduction of the extra parameters θ, δ and κ, the DETS (4) is more flexible and one can dynamically adjust the triggering intervals as well as the convergence rate through changing the three parameters.

Considering (1), (2), and ETC (3) obtains the error system

$$\begin{cases} \dot{e}_i(t) = E\dot{e}_i(t-\tau_1(t)) + \Re(e_i(t)) - R_i e_i(t) - \tilde{e}_i(t) \\ \qquad + \sum_{j=1}^{N} g_{ij} \Phi e_j(t) - \zeta \text{sign}(e_i(t)),\ t \in \mathcal{T}^{\rho}_{i,2k} \\ \dot{e}_i(t) = E\dot{e}_i(t-\tau_1(t)) + \Re(e_i(t)),\ t \in [t_{2k+1}, t_{2k+2}) \end{cases} \tag{5}$$

where $\Re(e_i(t)) = Ae_i(t) + BF(e_i(t)) + CH(e_i(t-\tau_2(t)))$, $e_i(t) = y_i(t) - x(t)$, $F(e_i(t)) = f(y_i(t)) - f(x(t))$ and $H(e_i(t-\tau_2(t))) = h(y_i(t-\tau_2(t))) - h(x(t-\tau_2(t)))$.

Main results: The following expressions will be used: $L^f = (l^f_{ij})_{n\times n}$, $L^h = (l^h_{ij})_{n\times n}$, $\Omega_{1i} = \mathbf{p}^T_i \widetilde{A} + \mathbf{p}^T_i |B| L^f + \mathbf{q}^T_i$, $\Omega_{2i} = \mathbf{p}^T_i g_{ii} \Phi + \sum_{j=1, j\neq i}^{N} \mathbf{p}^T_j |g_{ji}| \Phi - \mathbf{1}^T_n K_i$, $\Omega_{3i} = \mathbf{p}^T_i |C| L^h - (1-\mu_2) e^{-\xi\tau_2} \mathbf{q}^T_i$, $\Omega_{4i} = \mathbf{p}^T_i |E| - (1-\mu_1)\vartheta e^{-\xi\tau_1} \mathbf{p}^T_i$, $V(0) = \sum_{i=1}^{N} [(\mathbf{p}^T_i - \vartheta \mathbf{p}^T_i \text{diag}(\text{sign}(e_i(0))) \times \text{diag}\ (\text{sign}(\dot{e}_i(0))))|\ e_i(0)| + \int_{-\tau_1(0)}^{0} \vartheta e^{\xi s} \mathbf{p}^T_i |\ \dot{e}_i(s)|\ ds + \int_{-\tau_2(0)}^{0} e^{\xi s} \mathbf{q}^T_i | \times e_i(s)| ds]$, $\Psi(k, X) = \frac{1}{\xi} \ln(\xi X + 1) - \sum_{i=0}^{k-1} (1 - \frac{1}{\pi_i})(t_{2i+2} - t_{2i+1})$.

Theorem 1: For given positive constants ζ, ξ, η, θ, $\wp$, κ, $\vartheta \in (0,1)$ and $\delta > 1$, if there exist matrix $K_i \in \mathbb{R}^{n\times n}$ and vectors $\mathbf{p}^T_i = (p_{i1}, p_{i2}, \ldots, p_{in}) > 0$, $\mathbf{u}^T_i > 0$, $\mathbf{q}^T_i < 0$, $(i \in \mathbb{N}_N)$ such that

$$\Omega_{1i} + \Omega_{2i} + \xi(1+\vartheta)\mathbf{p}^T_i + \wp\sigma\mathbf{u}^T_i < 0 \tag{6}$$
$$\Omega_{1i} - \eta(1-\vartheta)\mathbf{p}^T_i < 0 \tag{7}$$
$$\Omega_{3i} < 0,\ \ \Omega_{4i} < c0 \tag{8}$$
$$\mathbf{p}^T_i - \wp\mathbf{u}^T_i < 0 \tag{9}$$
$$\widetilde{\zeta} = \zeta\lambda_{\min}(\mathbf{p}) - \wp\theta > 0 \tag{10}$$
$$\frac{\xi(t_{2k+1} - t_{2k})}{\eta(t_{2k+2} - t_{2k+1})} = \pi_k > 1 \tag{11}$$

then, the NTCN (2) with ETC (3) can be synchronized onto (1) in the desired time: $T(V(0)) = t_{2k_*} + \Psi_1(k_*, V(0)/\widetilde{\zeta})$, where $k_* = \max_{k\in\mathbb{N}} \times \{k | \Psi_1(k, V(0)/\widetilde{\zeta}) > 0\}$. The control gain R_i can be designed as $R_i = \mathbf{p}^{-1}_i K_i$ with $\mathbf{p}^{-1}_i = \text{diag}\{p^{-1}_{i1}, p^{-1}_{i2}, \ldots, p^{-1}_{in}\}$.

Proof: Choosing the following vector-based LKF candidate:

$$V(t) = V_1(t) + V_2(t) + V_3(t) \tag{12}$$

where $V_2(t) = \sum_{i=1}^{N} \int_{t-\tau_1(t)}^{t} \vartheta e^{\xi(s-t)} \mathbf{p}^T_i |\dot{e}_i(s)| ds$, $V_1(t) = \sum_{i=1}^{N} \mathbf{p}^T_i [I_n - \vartheta \text{diag}(\text{sign}(e_i(t))) \text{diag}(\text{sign}(\dot{e}_i(t)))] |e_i(t)|$, $V_3(t) = \sum_{i=1}^{N} \int_{t-\tau_2(t)}^{t} e^{\xi(s-t)} \mathbf{q}^T_i \times |e_i(s)| ds$.

Note that $V_1(t)$ is positive definite, known from the matrix $I_n - \vartheta \text{diag}(\text{sgn}(e_i(t))) \text{diag}(\text{sgn}(\dot{e}_i(t)))$ being a positive defined diagonal matrix since $\vartheta \in (0,1)$.

Let $v_1(t) = \dot{V}_1(t) + \sum_{i=1}^{N} \vartheta \mathbf{p}^T_i |\dot{e}_i(t)|$, simple calculation leads to

$$v_1(t) = \sum_{i=1}^{N}\sum_{j=1}^{n} \Big[p_{ij} \text{sign}(e_{ij}(t)) \dot{e}_{ij}(t) + \vartheta p_{ij} |\dot{e}_{ij}(t)| - \vartheta p_{ij} (\text{sign}(e_{ij}(t)))^2 |\dot{e}_{ij}(t)| \Big] = \sum_{i=1}^{N}\sum_{j=1}^{n} v_{1ij}(t). \tag{13}$$

Since $e_i(t) \neq \mathbf{0}_n$, it is concluded that there is at last one $j_0 \in \mathbb{N}_n$ such that $e_{ij_0}(t) \neq 0$. Without loss of generality, assume $e_{ij_0}(t) \neq 0$ and the other $e_{ij}(t) = 0$ for $j \in \mathbb{N}_n / j_0$. It obtains from (13) that

$$v_{1ij}(t) = \begin{cases} p_{ij_0} \text{sign}(e_{ij_0}(t)) \dot{e}_{ij_0}(t), & \text{for } j = j_0 \\ \vartheta p_{ij} |\dot{e}_{ij}(t)|, & \text{for } j \neq j_0. \end{cases} \tag{14}$$

Case 1: When $j = j_0$, according to the first equation of (5), (14) can be rewritten as follows:

$$\begin{aligned} v_{1ij_0}(t) \leq p_{ij_0} \Big[& g_{ii}\phi_{j_0} |e_{ij_0}(t)| + \sum_{l=1, l\neq i}^{N} |g_{il}| \phi_{j_0} |e_{lj_0}(t)| \\ & + \sum_{l=1}^{n} |\widetilde{e}_{j_0 l}| |\dot{e}_{il}(t-\tau_1(t))| + \sum_{l=1}^{n}\sum_{o=1}^{n} |b_{j_0 l}| l^f_{lo} |e_{io}(t)| \\ & + \sum_{l=1}^{n}\sum_{o=1}^{n} |c_{j_0 l}| l^h_{lo} |e_{io}(t-\tau_2(t))| + a_{j_0 j_0} |e_{ij_0}(t)| - \zeta \\ & + \sum_{l=1, l\neq j_0}^{n} |a_{j_0 l}| |e_{il}(t)| - r_{ij_0} |e_{ij_0}(t)| + |\tilde{e}_{ij_0}(t)| \Big]. \end{aligned} \tag{15}$$

Case 2: When $j \neq j_0$, recalling $e_{ij}(t) = 0$ when $j \neq j_0$, and $e_{ij_0}(t) \neq 0$ obtains from (14) that

$$\begin{aligned} v_{1ij}(t) \leq p_{ij} \Big[& g_{ii}\phi_j |e_{ij}(t)| + \sum_{l=1, l\neq i}^{N} |g_{il}| \phi_j |e_{lj}(t)| \\ & + \sum_{l=1}^{n} |\widetilde{e}_{jl}| |\dot{e}_{il}(t-\tau_1(t))| + \sum_{l=1}^{n}\sum_{o=1}^{n} |b_{jl}| l^f_{lo} |(e_{io}(t))| \\ & + a_{jj} |e_{ij}(t)| + \sum_{l=1, l\neq j}^{n} |a_{jl}| |e_{il}(t)| \\ & + \sum_{l=1}^{n} |c_{jl}| l^h_{lo} |e_{il}(t-\tau_2(t))| + |\tilde{e}_{ij_0}| \Big] \end{aligned} \tag{16}$$

where $0 < \vartheta < 1$ has been used.

Combining (15) with (16) leads to

$$\begin{aligned} v_1(t) \leq \sum_{i=1}^{N} \Big[& \mathbf{p}^T_i (\widetilde{A} + |B| L^f + g_{ii}\Phi - R_i) |e_i(t)| \\ & + \sum_{j=1, j\neq i}^{N} \mathbf{p}^T_i |g_{ij}| \Phi |e_j(t)| + \mathbf{p}^T_i |C| L^h |e_i(t-\tau_2(t))| \\ & + \mathbf{p}^T_i |E| |\dot{e}_i(t-\tau_1(t)| + \mathbf{p}^T_i |\tilde{e}_{ij_0}| - \zeta \mathbf{p}^T_i \gamma_i \Big] \end{aligned} \tag{17}$$

where $\widetilde{A} = (\tilde{a}_{ij})_{n\times n}, \tilde{a}_{ij} = a_{ij}$ for $i = j$ and $\tilde{a}_{ij} = |a_{ij}|$ for $i \neq j$, and $\gamma_i = (\gamma_{i1}, \gamma_{i2}, \ldots, \gamma_{in})^T$ with $\gamma_{ij} = 1$ if $e_{ij}(t) \neq 0$, otherwise $\gamma_{ij} = 0$, $i \in \mathbb{N}_n$, $j \in \mathbb{N}_N$.

Observed from the definition of $V_1(t)$ one has

$$0 \leq \sum_{i=1}^{N} \xi(1+\vartheta)\mathbf{p}^T_i |e_i(t)| - \xi V_1(t). \tag{18}$$

Based on the DETC (4), (17) and (18), and conditions (6), (8)–(10), the following inequality holds for $t \in [t_{2k}, t_{2k+1})$:

$$\dot{V}(t) \leq -\xi V(t) - \widetilde{\zeta}. \tag{19}$$

Similarly, when $t \in [t_{2k+1}, t_{2k+2})$, in view of (7) and (8), and one has

$$\dot{V}(t) \leq \eta V_1(t) \leq \eta V(t),\ t \in [t_{2k+1}, t_{2k+2}),\ k \in \mathbb{N}. \tag{20}$$

Following Lemma 2 in [7], it concludes that the NTCN (2) can achieve the FTS. ■

Remark 3: Both the intermittent coupling and intermittent control are considered simultaneously in Theorem 1. Note that, the intermittent coupling is aperiodic. Furthermore, due to the introduction of parameters ξ and η, the length of the coupling interval and decoupling interval can be adjusted flexibly as long as condition (11) holds. These are completely different from those in [1]–[3].

Remark 4: FTS criteria for the intermittently coupled NTCNs are presented in Theorem 1. Compared with [8], [9], the controller (3) is very simple and does not contain time delays, which is easy to implement in practice. Besides, the sufficient criteria obtained are formulated by vector inequalities. Due to introducing free vectors p_i^T and q_i^T, less conservative results are obtained than algebraic one.

Numerical example: An example is provided to explain the effectiveness of Theorem 1. The time-step size is taken as 0.001.

Consider system (1) with the following parameters: $x(t)=(x_1(t), x_2(t))^T$, $\tau_1(t)=0.85+0.15\sin(t)$, $\tau_2(t)=0.7-0.3\sin(t)$, $f(x(t))=(\tanh(x_1(t)),\tanh(x_2(t)))^T$, $h(x(t-\tau_2(t)))=0.5(|x_1(t-\tau_2(t))+1|-|x_1(t-\tau_2(t))-1|,|x_2(t-\tau_2(t))+1|-|x_2(t-\tau_2(t))-1|)^T$, $E=0.1\begin{pmatrix}0.1 & 0.2\\ 0.15 & 0.5\end{pmatrix}$, $A=\begin{pmatrix}0.7 & 1.5\\ 1.5 & -1\end{pmatrix}$, $B=\begin{pmatrix}3 & -0.4\\ -4 & -2\end{pmatrix}$, $C=\begin{pmatrix}-3.6 & 0.08\\ 0.24 & -3.2\end{pmatrix}$. Hence, one has $\tau_1=\tau_2=\tau_{\max}=1$, $\mu_1=0.15$ and $\mu_2=0.3$. Moreover, it is easy to check that $l_{ij}^f=1$, $l_{ij}^h=0.5$.

Then, an intermittently coupled network (2) including five nodes (1) is considered, in which the other relevant parameters are listed as $y_i(t)=(y_{i1}(t),y_{i2}(t))^T$, $i=1,2,\ldots,5$. $\Phi=\mathrm{diag}(1,1.2)$, and

$$G=0.1\begin{pmatrix}-3 & 1 & 0 & 1 & 1\\ 1 & -4 & 1 & 0 & 2\\ 1 & 1 & -4 & 2 & 2\\ 0 & 1 & 1 & -3 & 1\\ 1 & 0 & 2 & 1 & -4\end{pmatrix}.$$

Choose $\vartheta=0.1$, $\zeta=0.1$, $\xi=0.15$, $\eta=0.05$, $\theta=0.5$, $\delta=5.5$, $\kappa=2$, $\wp=0.0001$. The initial values of (2) are randomly chosen on $[-6,6]$, for $t\in[-1,0]$. The coupling intervals are took as $\prod=[4.2k, 4.2k+0.3)\cup[4.2k+1.1,4.2k+1.3)\cup[4.2k+1.8,4.2k+2.2)\cup[4.2k+3.2,4.2k+3.5)\cup\cdots,k\in\mathbb{N}$, and the decoupling intervals is $R^+/\prod$. Solving (6)–(11), obtains the feasible solutions $\mathbf{p}_i^T$, $\mathbf{q}_i^T$, $\mathbf{u}_i^T$ and control gain R_i (for space limitation, the feasible solutions are not listed here). According to Theorem 1, the settling time is estimated as $T(V(0))=38.0659$. The trajectory of the synchronization errors $e_i(t)$ without control is shown in Fig. 1. Fig. 2(a) shows the trajectory of the synchronization errors $e_i(t)$ with control; Fig. 2(b) shows the release instants and intervals of the DETS of each node.

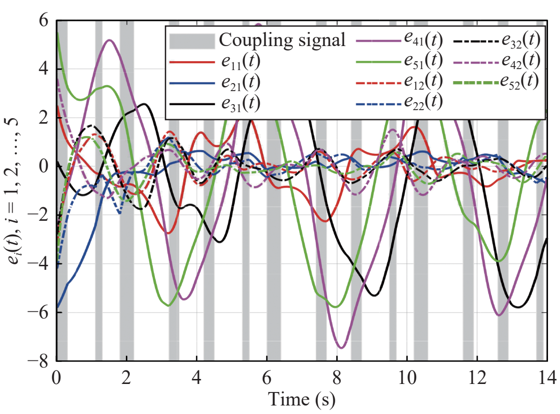

Fig. 1. Trajectory of the synchronization errors $e_i(t)$ without control.

Conclusion: FTS of NTCNs with intermittent couplings has been investigated. The ETC has been considered to reduce the unnecessary signal transmission, which can automatically exclude Zeno behavior. Considering a novel LKF with some free vectors, and several less conservative sufficient conditions formulated by vector inequalities have been obtained to ensure the FTS. The availability of the results has been demonstrated by the numerical examples.

Acknowledgments: This work was supported by the National Natural Science Foundation of China (62173231, 61903252) and Natural Science Foundation of Shanghai (21ZR444900).

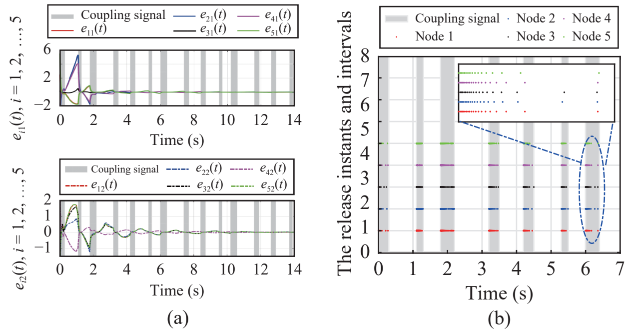

Fig. 2. Synchronization errors: (a) Trajectory of the synchronization errors $e_{i1}(t)$ and $e_{i2}(t)$; (b) The release instants and intervals.

References

[1] C. Hu, H. He, and H. Jiang, "Synchronization of complex-valued dynamic networks with intermittently adaptive coupling: A direct error method," *Automatica*, vol. 112, p. 108675, 2020.

[2] G. Wen, Z. Duan, W. Ren, *et al.*, "Distributed consensus of multi-agent systems with general linear node dynamics and intermittent communications," *Int. J. Robust Nonlin. Control*, vol. 24, no. 16, pp. 2438–2457, 2014.

[3] Y. Liu and H. Su, "Containment control of second-order multi-agent systems via intermittent sampled position data communication," *Appl. Math. Comput.*, vol. 362, p. 124522, 2019.

[4] D. Efimov, A. Polyakov, E. Fridman, *et al.*, "Comments on finite-time stability of time-delay systems," *Automatica*, vol. 50, no. 7, pp. 1944–1947, 2014.

[5] X. Yang, "Can neural networks with arbitrary delays be finite-timely synchronized?" *Neurocomputing*, vol. 143, pp. 275–281, 2014.

[6] Y. Zou, H. Su, R. Tang, *et al.*, "Finite-time bipartite synchronization of switched competitive neural networks with time delay via quantized control," *ISA Trans.*, vol. 125, pp. 156–165, 2022.

[7] R. Tang, H. Su, Y. Zou, *et al.*, "Finite-time synchronization of markovian coupled neural networks with delays via intermittent quantized control: Linear programming approach," *IEEE Trans. Neural Netw. Learn. Syst.*, vol. 33, no. 10, pp. 5268–5278, 2022.

[8] J. He, Y. Lin, M. Ge, *et al.*, "Adaptive finite-time cluster synchronization of neutral-type coupled neural networks with mixed delays," *Neurocomputing*, vol. 384, pp. 11–20, 2020.

[9] Z. Zhou, Z. Zhang, and M. Chen, "Finite-time synchronization for fuzzy delayed neutral-type inertial bam neural networks via the figure analysis approach," *Int. J. Fuzzy Syst.*, pp. 1–18, 2021.

[10] X. Yang, G. Feng, C. He, *et al.*, "Event-triggered dynamic output quantization control of switched ts fuzzy systems with unstable modes," *IEEE Trans. Fuzzy Syst.*, vol. 30, no. 10, pp. 4201–4210, 2022.

[11] X. Guo, D. Zhang, J. Wang, *et al.*, "Adaptive memory event-triggered observer-based control for nonlinear multi-agent systems under DoS attacks," *IEEE/CAA J. Autom. Sinica*, vol. 8, no. 10, pp. 1644–1656, 2021.

[12] J. Hu, C. Jia, H. Yu, *et al.*, "Dynamic event-triggered state estimation for nonlinear coupled output complex networks subject to innovation constraints," *IEEE/CAA J. Autom. Sinica*, vol. 9, no. 5, pp. 941–9446, 2022.

[13] A. Girard, "Dynamic triggering mechanisms for event-triggered control," *IEEE Trans. Autom. Control*, vol. 60, no. 7, pp. 1992–1997, 2014.

[14] J. Liu, Y. Wu, M. Sun, *et al.*, "Fixed-time cooperative tracking for delayed disturbed multi-agent systems under dynamic event-triggered control," *IEEE/CAA J. Autom. Sinica*, vol. 9, no. 5, pp. 930–933, 2022.

[15] J. Liu, G. Ran, Y. Huang, *et al.*, "Adaptive event-triggered finite-time dissipative filtering for interval type-2 fuzzy Markov jump systems with asynchronous modes," *IEEE Trans. Cybern.*, 2021. DOI: 10.1109/TCYB.2021.3053627

[16] Z. Fei, S. Shi, C. K. Ahn, *et al.*, "Finite-time control for switched T-S fuzzy systems via a dynamic event-triggered mechanism," *IEEE Trans. Fuzzy Syst.*, vol. 29, no. 12, pp. 3899–3909, 2020.