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RESEARCH ARTICLE

Event-Triggered Scheme for Networked Control Systems With Extended Dissipative Control and Cyber Attacks

LEI WANG[1], CHAO GE[2], RUONAN ZHANG[3], XINYUAN ZHANG[2], AND WEN GUO[2]
[1]Intelligence and Information Engineering School, Tangshan College, Tangshan 063009, China
[2]College of Electrical Engineering, North China University of Science and Technology, Tangshan 063000, China
[3]Shijiazhuang Maternity and Child Health Hospital, Shijiazhuang 050000, China

Corresponding authors: Chao Ge (gechao365@126.com) and Ruonan Zhang (764492119@qq.com)

ABSTRACT In this paper, an event-triggered transmission scheme for the networked control systems is investigated. The probabilistic cyber attacks and extended dissipative are considered in the systems. Firstly, an event-triggered transmission scheme with aperiodic sampling is proposed to establish a time-delay closed-loop system model. Then, a novel two-sided Lyapunov-Krasovskii functional is constructed by use of the characteristic of sawtooth structure. As a result, the sufficient conditions are derived in terms of linear matrix inequalities, which ensure the global stability of the networked control systems. The feedback controller gain matrix is figured out to guarantee the stability with extended dissipative. Finally, two numerical examples are given to illustrate the feasibility and effectiveness of the theoretical findings.

INDEX TERMS Event-triggered transmission scheme, networked control systems, extended dissipative, cyber attacks.

I. INTRODUCTION

At present, with the in-depth development of computer technology, network communication technology and control technology, networked control systems (NCSs) have been researched by scholars. Functional nodes such as sensor, controller, actuator and controlled objects are mainly included in NCSs. These plants are discretely distributed. Information interaction between these nodes can be realized through the digital network, especially remote information exchange [1], [2], [3], [4], [5]. However, the defects of the network also brought huge challenges, such as network-induced delays, packet loss, disorder, time-varying transmission interval and data quantification, which caused the instability of NCSs [6]. The control pattern based on periodic sampling mechanism (also called time-triggered) is used in the most of NCSs. All sampling signals are transmitted through the network, which will lead to occupancy of the resource. When the sampling period is selected, the requirement of system control performance needs to be satisfied in the worst case (e.g., the external disturbance factors, network-induced delays and packet loss are simultaneous [7], [8], [9], [10], [11]).

In order to deal with the problems of time-triggered mechanism, an event-triggered transmission scheme (ETTS) was proposed in the late 1990s [12]. In ETTS, when the trigger condition is satisfied, the sampled-data is sent by the trigger. The ETTS is an effective approach to reduce the data transmission. Compared with the traditional time-triggered method, ETTS can reduce the burden of network bandwidth occupation and the calculation cost of the controller [13], [14], [15]. In [16] and [17], the event triggers depend on the continuous monitoring of the system state to detect whether the current state exceeds the trigger threshold. The existing systems need to be overhauled in order to build this kind of triggers, which is difficult to realize. In these cases, a self-triggered scheme was proposed in [18], [19], [20], [21], and [22]. In [23], in order to ensure the stability of the L_2 finite gain for the generated self-triggered feedback systems, a new self-triggered scheme was proposed. This scheme could economize additional energy for the sensor and decrease the complexity of implementation. However, the design of a self-triggered controller was required more

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restraints on the system configuration. Since the predicted deadline depended on the system model which needed to be given in advance [22], the self-triggered scheme was hard to be applied. In [24] and [25], an event transmission scheme was proposed to transmit sampled-data whether or not. No special hardware was required in this scheme to continuously measure. Then, the periodic sampling system was modeled as a sampled-data error system. Peng et al. [26] proposed the non-periodic sampling event-triggered output-feedback control system based on [24]. Yan et al. [27] added quantification to the event-triggered NCSs based on periodic sampling. A network communication model was submitted including network conditions, status and event triggering strategies. The L_2 controller was designed simultaneously.

As we all know, the presence of external interference also affects the performance of the systems. The extended dissipation performance is introduced to guarantee the system stability. Extended dissipative analysis for the Markov jump system was proposed in [28]. The authors added the analysis of the $L_2 - L_\infty$ performance to traditional dissipation. Extended dissipative performance included the following special cases: H_∞, $L_2 - L_\infty$, passive, $(\mathcal{Q}, \mathcal{S}, \mathcal{R})$-dissipativity performance. Lee et al. [29] applied the extended dissipative analysis to the neural network systems. In [30] and [31], extended dissipative was applied to NCSs and network singular systems respectively.

Recently, the problem of cyber attacks for network security systems has been received more and more attention. It should be highlighted that in most of the NCSs, the cyber attacks occur naturally. The communication line may be destroyed. The system performance would be seriously affected by the malicious attacks [32], [33], [34]. Hence NCSs with cyber attacks have to be investigated. Deception attacks, replay attacks and denial-of-service (DoS) attacks have been mainly studied. Deception attacks send incorrect data to the sensor or network instead of the actual data to destroy the stability. In replay attack scenario the adversary does not have any model knowledge but is able to access and corrupt the sensor data. The replay attackers sent the repeated messages from the operator to the actuator. It is a particular kind of deception attack [35]. DoS attacks block the transmission of signals and data to damage the stability and operation. For example, Sathishkumar et al. [36] presented the dissipative control problem of singular NCSs with deception attacks. Wu et al. [37] described the guaranteed cost control problem of hybrid-triggered network systems under deception attacks. However, it should be noted that both deception attacks and extended dissipative for NCSs are rarely considered in previous papers, which is a intention of our study.

As far as the authors'known, few papers deal with the extended dissipative and deception attacks in the NCSs with ETTS motivated by above investigations. In this paper, we focus on the extended dissipative analysis of aperiodic sampling NCSs with ETTS and probabilistic deception attacks. The main contributions of this paper can be generalized as following:

(1) Both ETTS and stochastic deception attacks are considered in the NCSs with aperiodic sampling. A random variable satisfying Bernoulli distributed is used to govern the cyber attacks.

(2) An appropriate augmented two-sided Lyapunov-Krasovskii functional is constructed to acquire complete information about the actual sampling pattern.

(3) Several different performance indexes are unified in the extended dissipative analysis of NCSs. By adjusting the scalars and weighting matrices, the extended dissipative performance can be converted into four common performance indexes, which increases the comprehensiveness of the analysis results.

Notations: In this paper, $\mathbb{R}^n$ stands for the n-dimensional Euclidean space. $\mathbb{R}^m$ stands for the m-dimensional Euclidean space, the notation $\mathbb{E}$ refers to the mathematical expectation in Probability Theory. Moreover, the symbol $diag\{\ldots\}$ means a the block diagonal matrix and $col\{\ldots\}$ means the matrix column. Superscripts "T" and "-1" respectively stand for the transposition and the inverse of a matrix. "$*$" is used to denote the entries induced by symmetry. For $\omega(t) \in L_2[0, \infty)$, its norm is given by $\|\omega(t)\|_2 = \sqrt{\int_0^\infty \omega^T(t)\omega(t)dt}$, provided that it exists.

II. PROBLEM STATEMENT

A linear time-invariant plant is considered as:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + B_\omega \omega(t), \\ z(t) = Cx(t), \end{cases} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ is the state vector; $u(t) \in \mathbb{R}^m$ is the control input vector; $z(t) \in \mathbb{R}^m$ is the control output vector; $\omega(t) \in L_2[0, \infty)$ is the exogenous disturbance; A, B, B_ω, C are constant matrices with appropriate dimensions. The initial condition of system (1) is $x(0) = x_0$.

Assumption 1: Consider matrices Υ_1, Υ_2, Υ_3 and Υ_4 satisfying the conditions as follows:

(1) $\Upsilon_1 = \Upsilon_1^T \leq 0$, $\Upsilon_3 = \Upsilon_3^T > 0$, $\Upsilon_4 = \Upsilon_4^T \geq 0$,

(2) $(\| \Upsilon_1 \| + \| \Upsilon_2 \|)\Upsilon_4 = 0$.

Definition 1 [30]: For given matrices Υ_1, Υ_2, Υ_3, Υ_4 satisfying Assumption 1, any $t_f \geq 0$ and $\omega(t) \in L_2[0, \infty]$, system (1) is extended dissipative if the inequality is existed as follows:

$$\int_0^{t_f} \left(J(t) - \sup_{0 \leq t \leq t_f} z^T(t)\Upsilon_4 z(t) \right) dt \geq 0,$$

where

$$J(t) = z^T(t)\Upsilon_1 z(t) + 2z^T(t)\Upsilon_2\omega(t) + \omega^T(t)\Upsilon_3\omega(t).$$

Remark 1: The extended dissipative performance indices could be divided into the following four special cases. The matrices are set as follows:

(1) H_∞: $\Upsilon_1 = -I$, $\Upsilon_2 = 0$, $\Upsilon_3 = \gamma^2 I$, $\Upsilon_4 = 0$;

(2) $L_2 - L_\infty$: $\Upsilon_1 = 0$, $\Upsilon_2 = 0$, $\Upsilon_3 = \gamma^2 I$, $\Upsilon_4 = 0.09I$;

(3) Passivity: $\Upsilon_1 = 0$, $\Upsilon_2 = I$, $\Upsilon_3 = \gamma I$, $\Upsilon_4 = 0$;

(4) $(\mathcal{Q}, \mathcal{S}, \mathcal{R})$-dissipativity: $\Upsilon_1 = \mathcal{Q}, \Upsilon_2 = \mathcal{S}, \Upsilon_3 = \mathcal{R} - \beta I, \Upsilon_4 = 0$.

A sampled-data controller for system (1) is established as:

$$u(t) = Kx(t_k), \tag{2}$$

where K is the feedback controller gain.

In this part, an ETTS will be applied to produce the transmission events by means of the aperiodic sampled-data. When the sampling period is time-varying, researching the model formation, stability analysis and controller design are significative. The sampled-data error between the current sampling instant and the last triggered instant t_k is detected through the event generator. The next triggered instant t_{k+1} is designed as follows by ETTS:

$$t_{k+1} = t_k + \sum_{j=1}^{l-1} h_j + \inf_l \{h_l | e^T(i_l)\Phi e(i_l) \geq \delta x^T(t_k)\Phi x(t_k)\}, \tag{3}$$

where $e(i_l) = x(i_l) - x(t_k)$ denotes the state error, $i_l = t_k + \sum_{s=1}^{l} h_s$ is the current sampling instant, $l \in \mathcal{R}^+$. Define i_k as the next sampling instant. $h_l = i_k - i_l$ is an non-uniform sampling period as same as h_s. $\delta \in [0, 1)$ and Φ are the given threshold parameter and the designed positive weighting matrix, respectively. If the condition (3) is met, the transmission event is generated. From (3), it is obvious that the minimum transmission interval includes at least one sampling period, which prevents the Zeno behavior from happening.

Not all sampled-data need to be transmitted in ETTS, which is the difference with the time-triggered scheme. Only those satisfying the condition (3) can be transmitted. Moreover, the frequency of sampled-data transmission is determined by δ and Φ. When $\delta = 0$, the ETTS can be turned into a time-triggered scheme.

For introducing the ETTS at every sampling instant to decide whether the current sampled-data should be transmitted or not, we divide the holding interval Ω of the ZOH into subsets $\Omega_l = [i_l + \tau_{i_l}, i_l + h_{l+1} + \tau_{i_l+h_{l+1}}]$, that is $\Omega = \cup\Omega_l$ $(l = 0, 1, \ldots, t_{k+1} - t_k - 1)$. The τ_{i_l} and $\tau_{i_l+h_{l+1}}$ mean the transmission delay at different transmission instants. Define $\eta(t) = t - i_l$, $t \in \Omega_l$. The control law (2) is redefined as:

$$u(t) = K(x(t - \eta(t)) - e(i_l)), \quad t \in \Omega_l. \tag{4}$$

Assume that the lower and upper bounds of network-induced delay are known, that is, τ_1 and τ_2, respectively. Then based on the condition of $h_{l+1} + \tau_{i_l+h_{l+1}}$, the allowable sampling period can be set as:

$$h_m = \bar{\eta} - \tau_2 \leq h_l \leq h_M = \bar{\eta} - \tau_1. \tag{5}$$

The cyber attacks may occur in the network, since the network channel is unreliable. The attackers would attack at any moment. Therefore, the controller is rewritten as:

$$u(t) = (1 - \alpha(t))u_0(t) + \alpha(t)Kf(x(t - d(t))), \tag{6}$$

where $u_0(t) = K(x(t - \eta(t)) - e(i_l))$ and $f(x(t - d(t)))$ are the signal of cyber attacks, $d(t) \in [0, \bar{d}]$, $\alpha(t) \in \{0, 1\}$. $\alpha(t)$ is a Bernoulli distributed variable governing the probabilistic cyber attacks with $\text{Prob}\{\alpha(t) = 1\} = \alpha$, $\text{Prob}\ \{\alpha(t) = 0\} = 1 - \alpha$. The random variable $\alpha(t)$ describes whether the network is attacked. $\alpha(t) = 1$ signifies the attacks are appeared and $\alpha(t) = 0$ signifies the data can be transmitted normally through the network. Considering the above, the system (1) can be written as:

$$\begin{cases} \dot{x}(t) = \mathbb{A} + (\alpha - \alpha(t))\mathbb{B}, \\ z(t) = Cx(t), \end{cases} \tag{7}$$

where

$$\begin{cases} \mathbb{A} = & Ax(t) + (1 - \alpha)BK[x(t - \eta(t)) - e(i_l)] \\ & + \alpha BKf(x(t - d(t))) + B_\omega \omega(t), \\ \mathbb{B} = & BK[x(t - \eta(t)) - e(i_l)] - BKf(x(t - d(t))). \end{cases}$$

Assumption 2 [33]: For given constant matrix $F > 0$, the signal of cyber attacks $f(x(t - d(t)))$ satisfies

$$\| f(x(t - d(t))) \|_2 \leq \| Fx(t - d(t)) \|_2 .$$

Lemma 1 [38]: Given scalar $\theta \in (0, 1)$, matrix $H > 0 \in \mathbb{R}^{p\times p}$, matrices $M_1, M_2 \in \mathbb{R}^{p\times q}$, for all vector $\zeta \in \mathbb{R}^q$, if there exists the matrix $X \in \mathbb{R}^{p\times p}$ that satisfies $[\begin{smallmatrix} H & * \\ X & H \end{smallmatrix}]$, it can be established that

$$\frac{1}{\theta}\zeta^T M_1 J M_1 \zeta + \frac{1}{1-\theta}\zeta^T M_2 J M_2 \zeta \geq \begin{bmatrix} M_1\zeta \\ M_2\zeta \end{bmatrix}^T \begin{bmatrix} H & * \\ X & H \end{bmatrix} \begin{bmatrix} M_1\zeta \\ M_2\zeta \end{bmatrix}.$$

Lemma 2 [39]: Assume $0 \leq \eta(t) \leq \eta_M$ and Ψ_1, Ψ_2, Ψ are matrices with appropriate dimensions, then

$$\Psi + \eta(t)\Psi_1 + (\eta_M - \eta(t))\Psi_2 < 0,$$

if the following exist:

$$\begin{cases} \Psi + \eta_M\Psi_1 < 0, \\ \Psi + \eta_M\Psi_2 < 0. \end{cases}$$

III. MAIN RESULTS

In this section, sufficient conditions for the system (7) are derived to ensure the asymptotic stability.

Theorem 1: For given constants $\delta \in [0, 1)$, $\alpha \in [0, 1]$, $\bar{\eta} > 0$, $\bar{d} > 0$, and matrices $K, \Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4$, under the communication scheme (3), the system is mean-square asymptotically stable and extended dissipative, if there exist matrices $P > 0, Q_1 > 0, Q_2 > 0, R_1 > 0, R_2 > 0, \Phi > 0, S_3 > 0, , S_4 > 0, [\begin{smallmatrix} R_1 & * \\ U_1 & R_1 \end{smallmatrix}] > 0, [\begin{smallmatrix} R_2 & * \\ U_2 & R_2 \end{smallmatrix}] > 0$ and S_1, S_2, U_1, U_2, N_1 with appropriate dimensions such that

$$P - C^T\Upsilon_4 C \geq 0, \tag{8}$$

$$\begin{bmatrix} \Delta_{11} & * & * \\ \Delta_{21} & \Delta_{22} & * \\ \Delta_{31} & 0 & \Delta_{33} \end{bmatrix} < 0, \quad (s = 0, 1), \tag{9}$$

where

$$\begin{aligned}
\Delta_{11} &= \Pi_0+\Gamma_4+\Gamma_4^T+(1-s)\Pi_1+s\Pi_2,\\
\Delta_{21} &= col\{\bar{\eta}R_1\Gamma_1, \bar{d}R_2\Gamma_1, \bar{\eta}R_1\Gamma_6, \bar{d}R_2\Gamma_6, \Gamma_5\},\\
\Delta_{22} &= -diag\{R_1, R_2, R_1, R_2, I\},\\
\Delta_{31} &= col\{(1-s)\bar{\eta}S_3\Gamma_1+s\bar{\eta}N_1^T, (1-s)\bar{\eta}S_3\Gamma_6\},\\
\Delta_{33} &= -diag\{\bar{\eta}S_3, (1-s)\bar{\eta}S_3\},\\
\Pi_0 &= \begin{bmatrix} \grave{\Pi}_1 & * \\ \grave{\Pi}_2 & \grave{\Pi}_3 \end{bmatrix},\\
\grave{\Pi}_1 &= \begin{bmatrix} \Pi_{11} & * & * & * \\ \Pi_{21} & \Pi_{22} & * & * \\ \Pi_{31} & \Pi_{32} & \Pi_{33} & * \\ \Pi_{41} & 0 & 0 & \Pi_{44} \end{bmatrix},\\
\grave{\Pi}_2 &= \begin{bmatrix} \Pi_{51} & 0 & 0 & \Pi_{54} \\ \Pi_{61} & \Pi_{62} & 0 & 0 \\ \Pi_{71} & 0 & 0 & 0 \\ \Pi_{81} & 0 & 0 & 0 \end{bmatrix},\\
\grave{\Pi}_3 &= \begin{bmatrix} \Pi_{55} & * & * & * \\ 0 & \Pi_{66} & * & * \\ 0 & 0 & \Pi_{77} & * \\ 0 & 0 & 0 & \Pi_{88} \end{bmatrix},\\
\Pi_{11} &= PA+A^TP+Q_1+Q_2-S_1-S_1^T-R_1-R_2\\
&\quad -C^T\Upsilon_1C,\\
\Pi_{21} &= (1-\alpha)K^TB^TP+R_1-U_1-S_2^T+S_1,\\
\Pi_{22} &= -R_1+U_1+U_1^T+S_2+S_2^T-R_1+\delta\Phi,\\
\Pi_{31} &= U_1, \quad \Pi_{32} = -U_1+R_1,\\
\Pi_{33} &= -Q_1-R_1, \quad \Pi_{41} = R_2-U_2,\\
\Pi_{44} &= -R_2+U_2+U_2^T-R_2,\\
\Pi_{51} &= U_2, \quad \Pi_{54} = -U_2+R_2, \quad \Pi_{55} = -Q_2-R_2,\\
\Pi_{61} &= -(1-\alpha)K^TB^TP, \quad \Pi_{62} = -\delta\Phi,\\
\Pi_{66} &= (\delta-1)\Phi, \quad \Pi_{71} = \alpha K^TB^TP, \quad \Pi_{77} = -\alpha I,\\
\Pi_{81} &= B_\omega^TP-\Upsilon_2^TC, \quad \Pi_{88} = -\Upsilon_3,\\
\Pi_1 &= 2\bar{\eta}\Gamma_7^T\Gamma_1+\bar{\eta}\Gamma_2^TS_4\Gamma_2,\\
\Pi_2 &= -\bar{\eta}\Gamma_2^TS_4\Gamma_2,\\
\Gamma_1 &= \begin{bmatrix} A & \mathbb{B} & 0 & 0 & 0 & -\mathbb{B} & \alpha BK & B_\omega \end{bmatrix},\\
\Gamma_2 &= \begin{bmatrix} 0 & I & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\Gamma_3 &= \begin{bmatrix} 0 & 0 & 0 & I & 0 & 0 & 0 & 0 \end{bmatrix},\\
\Gamma_4 &= \begin{bmatrix} N_1 & -N_1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\Gamma_5 &= \begin{bmatrix} 0 & 0 & 0 & \sqrt{\alpha}F & 0 & 0 & 0 & 0 \end{bmatrix},\\
\Gamma_6 &= \begin{bmatrix} 0 & \mathbb{D} & 0 & 0 & 0 & -\mathbb{D} & \mathbb{D} & 0 \end{bmatrix},\\
\Gamma_7 &= \begin{bmatrix} S_1+S_1^T & S_2-S_1^T & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\mathbb{B} &= (1-\alpha)BK, \quad \mathbb{D} = \sqrt{\alpha(1-\alpha)}BK.
\end{aligned}$$

The following notations are defined to simplify writing.

$$\varrho_1(t) = x(t)-x(t-\eta(t)), \quad \varrho_2(t) = x(t-\eta(t))-x(t-\bar{\eta}),$$
$$\zeta_1(t) = x(t)-x(t-d(t)), \quad \zeta_2(t) = x(t-d(t))-x(t-\bar{d})$$

and the matrix $\xi^T(t) = [x^T(t), x^T(t-\eta(t)), x^T(t-\bar{\eta}), x^T(t-d(t)), x^T(t-\bar{d}), e^T(i_l), f^T(x(t-d(t))), \omega^T(t)]$.

The Lyapunov-Krasovskii functional candidate is constructed as follows:

$$V(t) = V_1(t)+V_2(t)+V_3(t), \tag{10}$$

where

$$\begin{aligned}
V_1(t) &= x^T(t)Px(t),\\
V_2(t) &= \int_{t-\bar{\eta}}^{t} x^T(v)Q_1x(v)dv + \int_{t-\bar{d}}^{t} x^T(v)Q_2x(v)dv\\
&\quad +\bar{\eta}\int_{t-\bar{\eta}}^{t}\int_{s}^{t} \dot{x}^T(v)R_1\dot{x}(v)dvds\\
&\quad +\bar{d}\int_{t-\bar{d}}^{t}\int_{s}^{t} \dot{x}^T(v)R_2\dot{x}(v)dvds,\\
V_3(t) &= 2(h_l-\eta(t))\varrho_1^T(t)[S_1x(t)+S_2x(t-\eta(t))]\\
&\quad +(h_l-\eta(t))\int_{t-\eta(t)}^{t} \dot{x}^T(v)S_3\dot{x}(v)dv\\
&\quad +(h_l-\eta(t))\eta(t)x^T(t-\eta(t))S_4x(t-\eta(t)).
\end{aligned}$$

Remark 2: In this paper, $V_3(t)$ is the two-sided functionals. We only need to ensure that they are positive definite at the sampled points. Their derivatives need to be negative definite during the sampling intervals. Not only $[i_l, t]$, but also $[t, i_k]$ is considered. This makes the results less conservative.

Taking the time derivative of $V(t)$ and expectation, we have

$$\begin{aligned}
E\{\dot{V}_1(t)\} &= 2E\{x^T(t)P\dot{x}(t)\},\\
E\{\dot{V}_2(t)\} &= x^T(t)(Q_1+Q_2)x(t)-x^T(t-\bar{\eta})Q_1x(t-\bar{\eta})\\
&\quad -x^T(t-\bar{d})Q_2x(t-\bar{d})+\bar{\eta}^2E\{\dot{x}^T(t)R_1\dot{x}(t)\}\\
&\quad +\bar{d}^2E\{\dot{x}^T(t)R_2\dot{x}(t)\}-\bar{\eta}\int_{t-\bar{\eta}}^{t} \dot{x}^T(s)R_1\dot{x}(s)ds\\
&\quad -\bar{d}\int_{t-\bar{d}}^{t} \dot{x}^T(s)R_2\dot{x}(s)ds,\\
E\{\dot{V}_3(t)\} &\leq -2\varrho_1^T(t)[S_1x(t)+S_2x(t-\eta(t))]\\
&\quad +E\{2(\bar{\eta}-\eta(t))\dot{x}^T(t)[S_1x(t)+S_2x(t-\eta(t))]\}\\
&\quad +E\{2(\bar{\eta}-\eta(t))\varrho_1^T(t)S_1\dot{x}(t)\}\\
&\quad -\int_{t-\eta(t)}^{t} \dot{x}^T(v)S_3\dot{x}(v)dv\\
&\quad +(\bar{\eta}-\eta(t))E\{\dot{x}^T(t)S_3\dot{x}(t)\}\\
&\quad -\eta(t)x^T(t-\eta(t))S_4x(t-\eta(t))\\
&\quad +(\bar{\eta}-\eta(t))x^T(t-\eta(t))S_4x(t-\eta(t)).
\end{aligned}$$

Notice that $E\{\alpha(t)\} = \alpha, E\{\alpha(t)-\alpha\} = 0, E\{(\alpha(t)-\alpha)^2\} = \alpha(1-\alpha)$, thus, we get

$$\begin{aligned}
E\{2x^T(t)P\dot{x}(t)\} &= 2x^T(t)P\mathbb{A},\\
E\{\dot{x}^T(t)R_1\dot{x}(t)\} &= \mathbb{A}^TR_1\mathbb{A}+\alpha(1-\alpha)\mathbb{B}^TR_1\mathbb{B},\\
E\{\dot{x}^T(t)R_2\dot{x}(t)\} &= \mathbb{A}^TR_2\mathbb{A}+\alpha(1-\alpha)\mathbb{B}^TR_2\mathbb{B},\\
E\{\dot{x}^T(t)S_3\dot{x}(t)\} &= \mathbb{A}^TS_3\mathbb{A}+\alpha(1-\alpha)\mathbb{B}^TS_3\mathbb{B}.
\end{aligned}$$

For $-\bar{\eta}\int_{t-\bar{\eta}}^{t}\dot{x}^T(s)R_1\dot{x}(s)ds$ and $-\bar{d}\int_{t-\bar{d}}^{t}\dot{x}^T(s)R_2\dot{x}(s)ds$, utilizing Lemma 1, we can get

$$-\bar{\eta}\int_{t-\bar{\eta}}^{t} \dot{x}^T(s)R_1\dot{x}(s)ds$$

$$\leq -\begin{bmatrix} \varrho_1(t) \\ \varrho_2(t) \end{bmatrix}^T \begin{bmatrix} R_1 & * \\ U_1 & R_1 \end{bmatrix} \begin{bmatrix} \varrho_1(t) \\ \varrho_2(t) \end{bmatrix}, \tag{11}$$

$$-\bar{d}\int_{t-\bar{d}}^{t} \dot{x}^T(s)R_2\dot{x}(s)ds$$
$$\leq -\begin{bmatrix} \zeta_1(t) \\ \zeta_2(t) \end{bmatrix}^T \begin{bmatrix} R_2 & * \\ U_2 & R_2 \end{bmatrix} \begin{bmatrix} \zeta_1(t) \\ \zeta_2(t) \end{bmatrix}. \tag{12}$$

For $-\int_{t-\eta(t)}^{t} \dot{x}^T(s)S_3\dot{x}(s)ds$, utilizing the Newton-Leibniz formula, for matrices N_1 with appropriate dimensions, we obtain

$$2\xi^T(t)N_1[x(t) - x(t-\eta(t)) - \int_{t-\eta(t)}^{t} \dot{x}(v)dv] = 0. \tag{13}$$

The following inequalities are established

$$-2\xi^T(t)N_1\int_{t-\eta(t)}^{t} \dot{x}(v)dv$$
$$\leq \eta(t)\xi^T(t)N_1S_3^{-1}N_1^T\xi(t) + \int_{t-\eta(t)}^{t} \dot{x}^T(v)S_3\dot{x}(v)dv. \tag{14}$$

From Assumption 2, it is clear that

$$\alpha x^T(t-d(t))F^TFx(t-d(t))$$
$$\geq \alpha f^T(x(t-d(t)))f(x(t-d(t))). \tag{15}$$

From (3), it is clear that

$$e^T(i_l)\Phi e(i_l) < \delta x^T(t_k)\Phi x(t_k). \tag{16}$$

Combining (11)-(16) together, we can figure out that

$$E\{\dot{V}(t) - J(t)\} \leq \xi^T(t)\Xi_0\xi(t), \tag{17}$$

where

$$\begin{aligned}
\Xi_0 &= \Pi_0 + (\bar{\eta} - \eta(t))\Xi_1 + \eta(t)\Xi_2 + \Gamma_5 + \Gamma_5^T \\
&\quad + \bar{\eta}^2\Gamma_1^TR_1\Gamma_1 + \bar{d}^2\Gamma_1^TR_2\Gamma_1 \\
&\quad + \bar{\eta}^2\Gamma_6^TR_1\Gamma_6 + \bar{d}^2\Gamma_6^TR_2\Gamma_6, \\
\Xi_1 &= 2\Gamma_7^T\Gamma_1 + \Gamma_2^TS_4\Gamma_2 + \Gamma_1^TS_3\Gamma_1 + \Gamma_6^TS_3\Gamma_6, \\
\Xi_2 &= -\Gamma_2^TS_4\Gamma_2 + N_1S_3^{-1}N_1^T.
\end{aligned}$$

Using Lemma 2 and Schur complement, $\Xi_0 < 0$ is a convex combination of Ξ_1, Ξ_2, Ξ_3 and Ξ_4. Then, we can get

$$E\{\dot{V}(t)\} \leq E\{J(t)\}. \tag{18}$$

Integrating both side of (18) from 0 to $t \geq 0$, the following inequation can be received

$$E\left\{\int_0^t J(s)ds\right\} \geq E\{V(t) - V(0)\} \geq E\{x^T(t)Px(t)\}. \tag{19}$$

Based on Definition 1, we can represent the H_∞, passivity and $(\mathcal{Q}, \mathcal{S}, \mathcal{R})$-dissipativity performance conditions when $\Upsilon_4 = 0$ and the $L_2 - L_\infty$ performance criterion when $\Upsilon_4 > 0$.

Firstly, considering $\Upsilon_4 = 0$, we can obtain

$$E\left\{\int_0^t J(s)ds\right\} \geq 0. \tag{20}$$

Then, we consider $\Upsilon_4 > 0$ and the matrices $\Upsilon_1 = 0$, $\Upsilon_2 = 0$ and $\Upsilon_3 > 0$ in Assumption 1. For any $0 \leq t \leq t_f$ and considering (19), we can obtain $E\{\int_0^{t_f} J(s)ds\} \geq E\{\int_0^t J(s)ds\} \geq E\{x^T(t)Px(t)\}$. Therefore, according to (8), we have

$$E\{z^T(t)\Upsilon_4z(t)\} = E\{x^TC^T\Upsilon_4Cx(t)\}$$
$$\leq E\{x^T(t)Px(t)\} \leq E\left\{\int_0^{t_f} J(s)ds\right\}.$$

Considered the two cases of $\Upsilon_4 = 0$ and $\Upsilon_4 > 0$, the system (7) is asymptotically stable with extended dissipative for $\omega(t) \in L_2[0, \infty]$. This is the end of the proof.

Using Theorem 1, the feedback controller gain K is derived under the ETTS.

Theorem 2: For given constants $\delta \in [0, 1)$, $\alpha \in [0, 1]$, $\bar{\eta} > 0$, $\bar{d} > 0$, and matrices Υ_1, Υ_2, Υ_3, Υ_4, under the communication scheme (3), the system is mean-square asymptotically stable and extended dissipative with a state feedback gain $K = YX^{-T}$, if there exist positive scalars λ, matrices $X > 0$, $\hat{Q}_1 > 0$, $\hat{Q}_2 > 0$, $\hat{R}_1 > 0$, $\hat{R}_2 > 0$, $\hat{S}_3 > 0$, $\hat{S}_4 > 0$, $\hat{\Phi} > 0$, $[\begin{smallmatrix} \hat{R}_1 & * \\ \hat{U}_1 & \hat{R}_1 \end{smallmatrix}] > 0$, $[\begin{smallmatrix} \hat{R}_2 & * \\ \hat{U}_2 & \hat{R}_2 \end{smallmatrix}] > 0$ and $\hat{S}_1$, $\hat{S}_2$, $\hat{U}_1$, $\hat{U}_2$, $\hat{N}_1$, Y with appropriate dimensions such that

$$\begin{bmatrix} X & * \\ CX & \Upsilon_4^{-1} \end{bmatrix} \geq 0, \tag{21}$$

$$\begin{bmatrix} \Omega_{11} & * & * & * \\ \Omega_{21} & \Omega_{22} & * & * \\ \Omega_{31}^s & 0 & \Omega_{33}^s & * \\ \Omega_{41}^s & 0 & 0 & \Omega_{44}^s \end{bmatrix} < 0, \quad (s = 0, 1), \tag{22}$$

where

$$\begin{aligned}
\Omega_{11} &= \hat{\Pi}_0 + \hat{\Gamma}_4 + \hat{\Gamma}_4^T + (1-s)\hat{\Pi}_1 + s\hat{\Pi}_2, \\
\Omega_{21} &= col\{\bar{\eta}\hat{\Gamma}_1, \bar{d}\hat{\Gamma}_1, \bar{\eta}\hat{\Gamma}_6, \bar{d}\hat{\Gamma}_6, \hat{\Gamma}_5\}, \\
\Omega_{22} &= -diag\{X\hat{R}_1^{-1}X, X\hat{R}_2^{-1}X, X\hat{R}_1^{-1}X, X\hat{R}_2^{-1}X, I\}, \\
\Omega_{31}^s &= col\{(1-s)\bar{\eta}\hat{\Gamma}_1 + s\bar{\eta}\hat{N}_1^T, (1-s)\bar{\eta}\hat{\Gamma}_6, \\
\Omega_{33}^s &= -diag\{(1-s)\bar{\eta}X\hat{S}_3^{-1}X + s\bar{\eta}\hat{S}_3, (1-s)\bar{\eta}X\hat{S}_3^{-1}X, \}, \\
\Omega_{41}^s &= col\{(1-s)\hat{\Gamma}_1, (1-s)\bar{\eta}\hat{\Gamma}_7, CX\Gamma_9\}, \\
\Omega_{44}^s &= -diag\{(1-s)\lambda_1 I, (1-s)X\lambda_1^{-1}X, -\Upsilon_1^{-1}\},
\end{aligned}$$

$$\hat{\Pi}_0 = \begin{bmatrix} \hat{\hat{\Pi}}_1 & * \\ \hat{\hat{\Pi}}_2 & \hat{\hat{\Pi}}_3 \end{bmatrix},$$

$$\hat{\hat{\Pi}}_1 = \begin{bmatrix} \hat{\Pi}_{11} & * & * & * \\ \hat{\Pi}_{21} & \hat{\Pi}_{22} & * & * \\ \hat{\Pi}_{31} & \hat{\Pi}_{32} & \hat{\Pi}_{33} & * \\ \hat{\Pi}_{41} & 0 & 0 & \hat{\Pi}_{44} \end{bmatrix},$$

$$\hat{\hat{\Pi}}_2 = \begin{bmatrix} \hat{\Pi}_{51} & 0 & 0 & \hat{\Pi}_{54} \\ \hat{\Pi}_{61} & \hat{\Pi}_{62} & 0 & 0 \\ \hat{\Pi}_{71} & 0 & 0 & 0 \\ \hat{\Pi}_{81} & 0 & 0 & 0 \end{bmatrix},$$

$$\hat{\hat{\Pi}}_3 = \begin{bmatrix} \hat{\Pi}_{55} & * & * & * \\ 0 & \hat{\Pi}_{66} & * & * \\ 0 & 0 & \hat{\Pi}_{77} & * \\ 0 & 0 & 0 & \hat{\Pi}_{88} \end{bmatrix},$$

$$
\begin{aligned}
\hat{\Pi}_{11} &= AX + XA^T + \hat{Q}_1 + \hat{Q}_2 - \hat{S}_1 - \hat{S}_1^T - \hat{R}_1 - \hat{R}_2,\\
\hat{\Pi}_{21} &= (1-\alpha)Y^T B^T + \hat{R}_1 - \hat{U}_1 - \hat{S}_2^T + \hat{S}_1,\\
\hat{\Pi}_{22} &= -\hat{R}_1 + \hat{U}_1 + \hat{U}_1^T + \hat{S}_2 + \hat{S}_2^T - \hat{R}_1 + \delta\hat{\Phi},\\
\hat{\Pi}_{31} &= \hat{U}_1, \quad \hat{\Pi}_{32} = -\hat{U}_1 + \hat{R}_1, \quad \hat{\Pi}_{33} = -\hat{Q}_1 - \hat{R}_1,\\
\hat{\Pi}_{41} &= \hat{R}_2 - \hat{U}_2,\\
\hat{\Pi}_{44} &= -\hat{R}_2 + \hat{U}_2 + \hat{U}_2^T - \hat{R}_2,\\
\hat{\Pi}_{51} &= \hat{U}_2, \quad \hat{\Pi}_{54} = -\hat{U}_2 + \hat{R}_2, \quad \hat{\Pi}_{55} = -\hat{Q}_2 - \hat{R}_2,\\
\hat{\Pi}_{61} &= -(1-\alpha)Y^T B^T, \hat{\Pi}_{62} = -\delta\hat{\Phi}, \hat{\Pi}_{66} = (\delta - 1)\hat{\Phi},\\
\hat{\Pi}_{71} &= \alpha Y^T B^T, \quad \hat{\Pi}_{77} = -X\alpha X,\\
\hat{\Pi}_{81} &= B_\omega^T - \Upsilon_2^T CX, \quad \hat{\Pi}_{88} = -\Upsilon_3,\\
\hat{\Pi}_1 &= \bar{\eta}\Gamma_3^T \hat{S}_4 \Gamma_3, \quad \hat{\Pi}_2 = -\bar{\eta}\Gamma_3^T \hat{S}_4 \Gamma_3,\\
\hat{\Gamma}_1 &= \begin{bmatrix} AX & \hat{\mathbb{B}} & 0 & 0 & 0 & -\hat{\mathbb{B}} & \alpha BY & B_\omega \end{bmatrix},\\
\hat{\Gamma}_4 &= \begin{bmatrix} \hat{N}_1 & -\hat{N}_1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\hat{\Gamma}_5 &= \begin{bmatrix} 0 & 0 & 0 & \sqrt{\alpha}FX & 0 & 0 & 0 & 0 \end{bmatrix},\\
\hat{\Gamma}_6 &= \begin{bmatrix} 0 & \hat{\mathcal{B}} & 0 & 0 & 0 & -\hat{\mathcal{B}} & \hat{\mathcal{B}} & 0 \end{bmatrix},\\
\hat{\Gamma}_7 &= \begin{bmatrix} \hat{S}_1 + \hat{S}_1^T & \hat{S}_2 - \hat{S}_1^T & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\Gamma_9 &= \begin{bmatrix} I & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\\
\hat{\mathbb{B}} &= (1-\alpha)BY, \quad \hat{\mathcal{B}} = \sqrt{\alpha(1-\alpha)}BY.
\end{aligned}
$$

Define $Y = KX, X = P^{-1}, XQ_1X = \hat{Q}_1, XQ_2X = \hat{Q}_2, XR_1X = \hat{R}_1, XR_2X = \hat{R}_2, XS_1X = \hat{S}_1, XS_2X = \hat{S}_2, XS_3X = \hat{S}_3, XS_4X = \hat{S}_4, X\Phi X = \hat{\Phi}, XU_1X = \hat{U}_1, XU_2X = \hat{U}_2, XN_1X = \hat{N}_1$. For any scalars $\lambda_1, \lambda_2 > 0$, it follows that

$$2\eta\Gamma_7^T\Gamma_1 \leq \Gamma_1^T\lambda_1^{-1}\Gamma_1 + \bar{\eta}^2\Gamma_7^T\lambda_1\Gamma_7.$$

Then pre- and post-multipiying both sides of (8) with X and (8) with $diag\{\mathbb{X}, I, I, I, I\}$ $(s = 0)$ and $diag\{\mathbb{X}, X\}$ $(s = 1)$, respectively, where $\mathbb{X} = diag\{X, X, X, X, X, X, X, I, I, I, I, I, I\}$.

By Schur complement, we can obtain non-convex matrix inequalities (21) and (22), which include nonlinear items $X\alpha X, X\hat{R}_1^{-1}X, X\hat{R}_2^{-1}X, X\hat{S}_3^{-1}X$, and $X\lambda^{-1}X$.

Remark 3: It should be noted that (22) is non-convex. Hence, (22) is failed to be resolved by LMIs approach. In this note, we use a simple linear approach and a cone complementarity linearization (CCL) [40] method to deal with the nonlinear items. We can obtain

$$
\begin{aligned}
-X\alpha X &\leq \rho_1^2\alpha^{-1}I - 2\rho_1 X,\\
-X\hat{R}_1^{-1}X &\leq \rho_2^2\hat{R}_1 - 2\rho_2 X,\\
-X\hat{R}_2^{-1}X &\leq \rho_3^2\hat{R}_1 - 2\rho_3 X,\\
-X\hat{S}_3^{-1}X &\leq \rho_4^2\hat{S}_3 - 2\rho_4 X.
\end{aligned}
$$

For $X\lambda^{-1}X$, we define G such that

$$X\lambda^{-1}X > G. \tag{23}$$

Then, the solvability of (22) can be replaced by (22)', where (22)' is derived from (22) by replacing these nonlinear items and (23). The above minimization problem can be solved by a CCL algorithm.

By Schur complement, (23) is equivalent to

$$\begin{bmatrix} \lambda^{-1}I & * \\ X^{-1} & G^{-1} \end{bmatrix} > 0. \tag{24}$$

Define $\bar{\lambda}I = \lambda^{-1}I, \bar{G} = G^{-1}, \bar{X} = X^{-1}$. Then, we provide the following linearization algorithm for Theorem 2.

Algorithm 1:

Step 1: Find a feasible solution $\{X, \bar{X}, \bar{\lambda}I, \lambda I, \bar{G}, G\}$ to LMIs (22)' and

$$
\begin{bmatrix} \bar{\lambda}I & * \\ \bar{X} & \bar{G} \end{bmatrix} > 0, \quad \begin{bmatrix} \lambda I & * \\ I & \bar{\lambda}I \end{bmatrix} \geq 0,
$$
$$
\begin{bmatrix} G & * \\ I & \bar{G} \end{bmatrix} \geq 0, \quad \begin{bmatrix} X & * \\ I & \bar{X} \end{bmatrix} \geq 0.
$$

Set $k = 0$.

Step 2: Solve the following minimization problem:

$$min \quad tr(G_k\bar{G} + \bar{G}_kG + \lambda_k\bar{\lambda} + \bar{\lambda}_k\lambda + X_k\bar{X} + \bar{X}_kX),$$

subject to LMIs (22)'.

Step 3: If (22)' is satisfied, a controller is given by $K = YX^{-T}$. Otherwise, set $k = k + 1$, if $k < n$, go to step 2; otherwise, EXIT (There is no result).

If the extended dissipative and external disturbance are not existed, the following corollary could be obtained by Theorem 2.

Corollary 1: For given constants $\delta \in [0, 1), \alpha \in [0, 1], \bar{\eta} > 0, \bar{d} > 0$, under the communication scheme (3), the system is mean-square asymptotically stable with a state feedback gain $K = YX^{-T}$, if there exist positive scalars λ, matrices $X > 0, \hat{Q}_1 > 0, \hat{Q}_2 > 0, \hat{R}_1 > 0, \hat{R}_2 > 0, \hat{S}_3 > 0, \hat{S}_4 > 0, \hat{\Phi} > 0, [\begin{smallmatrix} \hat{R}_1 & * \\ \hat{U}_1 & \hat{R}_1 \end{smallmatrix}] > 0, [\begin{smallmatrix} \hat{R}_2 & * \\ \hat{U}_2 & \hat{R}_2 \end{smallmatrix}] > 0$ and $\hat{S}_1, \hat{S}_2, \hat{U}_1, \hat{U}_2, \tilde{N}_1, Y$ with appropriate dimensions such that

$$\begin{bmatrix} \tilde{\Omega}_{11} & * & * & * \\ \tilde{\Omega}_{21} & \tilde{\Omega}_{22} & * & * \\ \tilde{\Omega}_{31}^s & 0 & \tilde{\Omega}_{33}^s & * \\ \tilde{\Omega}_{41}^s & 0 & 0 & \tilde{\Omega}_{44}^s \end{bmatrix} < 0, \quad (s = 0, 1),$$

where

$$
\begin{aligned}
\tilde{\Omega}_{11} &= \hat{\Pi}_0 + \tilde{\Gamma}_4 + \tilde{\Gamma}_4^T + (1-s)\tilde{\Pi}_1 + s\tilde{\Pi}_2,\\
\tilde{\Omega}_{21} &= col\{\bar{\eta}\tilde{\Gamma}_1, \bar{d}\tilde{\Gamma}_1, \bar{\eta}\tilde{\Gamma}_6, \bar{d}\tilde{\Gamma}_6, \tilde{\Gamma}_5\},\\
\tilde{\Omega}_{22} &= -diag\{X\hat{R}_1^{-1}X, X\hat{R}_2^{-1}X, X\hat{R}_1^{-1}X, X\hat{R}_2^{-1}X, I\},\\
\tilde{\Omega}_{31}^s &= col\{(1-s)\bar{\eta}\tilde{\Gamma}_1 + s\bar{\eta}\tilde{N}_1^T, (1-s)\bar{\eta}\tilde{\Gamma}_6\},\\
\tilde{\Omega}_{33}^s &= -diag\{(1-s)\bar{\eta}X\hat{S}_3^{-1}X + s\bar{\eta}\hat{S}_3, (1-s)\bar{\eta}X\hat{S}_3^{-1}X\},\\
\tilde{\Omega}_{41}^s &= col\{(1-s)\tilde{\Gamma}_1, (1-s)\bar{\eta}\tilde{\Gamma}_7\},\\
\tilde{\Omega}_{44}^s &= -diag\{(1-s)\lambda_1 I, (1-s)X\lambda_1^{-1}X\},
\end{aligned}
$$

$$\tilde{\Pi}_0 = \begin{bmatrix} \hat{\Pi}_{11} & * & * & * & * & * & * \\ \hat{\Pi}_{21} & \hat{\Pi}_{22} & * & * & * & * & * \\ \hat{\Pi}_{31} & \hat{\Pi}_{32} & \hat{\Pi}_{33} & * & * & * & * \\ \hat{\Pi}_{41} & 0 & 0 & \hat{\Pi}_{44} & * & * & * \\ \hat{\Pi}_{51} & 0 & 0 & \hat{\Pi}_{54} & \hat{\Pi}_{55} & * & * \\ \hat{\Pi}_{61} & \hat{\Pi}_{62} & 0 & 0 & 0 & \hat{\Pi}_{66} & * \\ \hat{\Pi}_{71} & 0 & 0 & 0 & 0 & 0 & \hat{\Pi}_{77} \end{bmatrix},$$

$$\tilde{\Pi}_1 = \bar{\eta}\tilde{\Gamma}_2^T\hat{S}_4\tilde{\Gamma}_2, \quad \tilde{\Pi}_2 = -\bar{\eta}\tilde{\Gamma}_2^T\hat{S}_4\tilde{\Gamma}_2,$$

$$\tilde{\Gamma}_1 = \begin{bmatrix} AX & \hat{\mathbb{B}} & 0 & 0 & 0 & -\hat{\mathbb{B}} & \alpha BY \end{bmatrix},$$

$$\tilde{\Gamma}_2 = \begin{bmatrix} 0 & I & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$\tilde{\Gamma}_3 = \begin{bmatrix} 0 & 0 & 0 & I & 0 & 0 & 0 \end{bmatrix},$$

$$\tilde{\Gamma}_4 = \begin{bmatrix} \tilde{N}_1 & -\tilde{N}_1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$\tilde{\Gamma}_5 = \begin{bmatrix} 0 & 0 & 0 & \sqrt{\alpha}FX & 0 & 0 & 0 \end{bmatrix},$$

$$\tilde{\Gamma}_6 = \begin{bmatrix} 0 & \hat{\mathbb{B}} & 0 & 0 & 0 & -\hat{\mathbb{B}} & \hat{\mathbb{B}} \end{bmatrix},$$

$$\tilde{\Gamma}_7 = \begin{bmatrix} \hat{S}_1 + \hat{S}_1^T & \hat{S}_2 - \hat{S}_1^T & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

When $\alpha(t) = 0$, there are no cyber attacks. The system (7) is rewritten as:

$$\dot{x}(t) = Ax(t) + BKx(t - \eta(t)) - BKe(i_l) + B_\omega \omega(t).$$

The following corollary may be expected by Theorem 2.

Corollary 2: For given constants $\delta \in [0, 1)$, $\bar{\eta} > 0$, and matrices $\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4$, under the communication scheme (3), the system is mean-square asymptotically stable and extended dissipative with a state feedback gain $K = YX^{-T}$, if there exist positive scalar λ, matrices $X > 0$, $\hat{Q}_1 > 0$, $\hat{R}_1 > 0$, $\hat{S}_3 > 0$, $\hat{S}_4 > 0$, $\hat{\Phi} > 0$, $\left[\begin{smallmatrix} \hat{R}_1 & * \\ \hat{U}_1 & \hat{R}_1 \end{smallmatrix}\right] > 0$ and $\hat{U}_1, \bar{\bar{N}}_1, Y$ with appropriate dimensions such that

$$\begin{bmatrix} X & * \\ CX & \Upsilon_4^{-1} \end{bmatrix} \geq 0,$$

$$\begin{bmatrix} \bar{\bar{\Pi}}_0 + \bar{\bar{\Gamma}}_4 + \bar{\bar{\Gamma}}_4^T + (1-s)\bar{\bar{\Pi}}_1 + s\bar{\bar{\Pi}}_2 & * \\ \Omega_{21}^s & \Omega_{22}^s \end{bmatrix} < 0, \quad (s=0, 1),$$

where

$$\bar{\bar{\Pi}}_0 = \begin{bmatrix} \bar{\bar{\Pi}}_{11} & * & * & * & * \\ \bar{\bar{\Pi}}_{21} & \bar{\bar{\Pi}}_{22} & * & * & * \\ \hat{\Pi}_{31} & \hat{\Pi}_{32} & \hat{\Pi}_{33} & * & * \\ \bar{\bar{\Pi}}_{41} & \bar{\bar{\Pi}}_{42} & 0 & \bar{\bar{\Pi}}_{44} & * \\ \bar{\bar{\Pi}}_{51} & 0 & 0 & 0 & \bar{\bar{\Pi}}_{55} \end{bmatrix},$$

$$\bar{\bar{\Omega}}_{21}^0 = col\{\bar{\eta}\bar{\bar{\Gamma}}_1, \bar{\eta}\bar{\bar{\Gamma}}_1, \bar{\bar{\Gamma}}_1, \bar{\eta}\bar{\bar{\Gamma}}_5, CX\bar{\bar{\Gamma}}_2\},$$

$$\bar{\bar{\Omega}}_{22}^0 = -diag\{X\hat{R}_1^{-1}X, \bar{\eta}X\hat{S}_3^{-1}X, \lambda I, X\lambda^{-1}X, -\Upsilon_1^{-1}\},$$

$$\bar{\bar{\Omega}}_{21}^1 = col\{\bar{\eta}\bar{\bar{\Gamma}}_1, \bar{\eta}\bar{\bar{N}}_1^T, CX\bar{\bar{\Gamma}}_2\},$$

$$\bar{\bar{\Omega}}_{22}^1 = -diag\{X\hat{R}_1^{-1}X, \bar{\eta}\hat{S}_3, -\Upsilon_1^{-1}\},$$

$$\bar{\bar{\Pi}}_{11} = AX + XA^T + \hat{Q}_1 - \hat{S}_1 - \hat{S}_1^T - \hat{R}_1,$$

$$\bar{\bar{\Pi}}_{21} = Y^TB^T + \hat{R}_1 - \hat{U}_1 - \hat{S}_2^T + \hat{S}_1,$$

$$\bar{\bar{\Pi}}_{22} = -\hat{R}_1 + \hat{U}_1 + \hat{U}_1^T + \hat{S}_2 + \hat{S}_2^T - \hat{R}_1 + \delta\hat{\Phi},$$

$$\bar{\bar{\Pi}}_{41} = -Y^TB^T, \quad \bar{\bar{\Pi}}_{42} = -\delta\hat{\Phi}, \quad \bar{\bar{\Pi}}_{44} = -(1-\delta)\hat{\Phi},$$

$$\bar{\bar{\Pi}}_{51} = B_\omega^T - \Upsilon_2^T CX, \quad \bar{\bar{\Pi}}_{55} = -\Upsilon_3,$$

$$\bar{\bar{\Pi}}_1 = \bar{\eta}\bar{\bar{\Gamma}}_3^T\hat{S}_4\bar{\bar{\Gamma}}_3,$$

$$\bar{\bar{\Pi}}_2 = -\bar{\eta}\bar{\bar{\Gamma}}_3^T\hat{S}_4\bar{\bar{\Gamma}}_3,$$

$$\bar{\bar{\Gamma}}_1 = \begin{bmatrix} AX & BY & 0 & -BY & B_\omega \end{bmatrix},$$

$$\bar{\bar{\Gamma}}_2 = \begin{bmatrix} I & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\bar{\Gamma}}_3 = \begin{bmatrix} 0 & I & 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\bar{\Gamma}}_4 = \begin{bmatrix} \bar{\bar{N}}_1 & -\bar{\bar{N}}_1 & 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\bar{\Gamma}}_5 = \begin{bmatrix} \tilde{S}_1 + \tilde{S}_1^T & \tilde{S}_2 - \tilde{S}_1^T & 0 & 0 & 0 \end{bmatrix}.$$

IV. NUMERICAL EXAMPLES

In this section, we provide two numerical examples to demonstrate the effectiveness of the proposed method.

Example 1: Consider a model with the following parameters:

$$A = \begin{bmatrix} 0 & 1 \\ -2 & 3 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \quad K = \begin{bmatrix} 1 & 4 \end{bmatrix}.$$

In this example, the system with ETTS is $\omega(t) = 0$, and $\alpha(t) = 0$. From Theorem 1, we can get the different δ corresponding to the upper bound of $\bar{\eta}$ in Table 1. The stability of the networked control system is verified.

TABLE 1. Different δ corresponding to the upper bound of $\bar{\eta}$.

δ	[26]	Theorem 1
0.003	0.3029	0.4887
0.0273	0.1484	0.4278
0.0588	0.1927	0.3829

From Table 1, we can get that the upper bound of $\bar{\eta}$ is larger than the one in [26], which means that the results of our method using a novel LKF are less conservative and more generalizable.

Example 2 The following parameter matrices [30] is considered in the system:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{-mg}{M} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & \frac{g}{l} & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ \frac{1}{M} \\ 0 \\ -\frac{1}{Ml} \end{bmatrix},$$

$$C = B_\omega^T = \begin{bmatrix} 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix},$$

where $M = 10kg$, $m = 1kg$, $l = 3m$ and $g = 10m/s^2$.

The initial state is $x_0 = [0.98, 0, 0.2, 0]$. Set $\omega(t) = 0.01\sin(2\pi t)$. The networked control structure is shown in Fig.1.

Set $\delta = 0.2$, $\rho_2 = \rho_4 = 1$ and $\gamma = 200$ in Case 1, Case 2, Case 3, $\beta = -500$ in Case 4.

By solving Corollary 2 with MATLAB toolbox and the parameters in Table 2, we can get the upper bound for $\bar{\eta}$ in Table 3, where SP is Sampled Points, TP is transmission

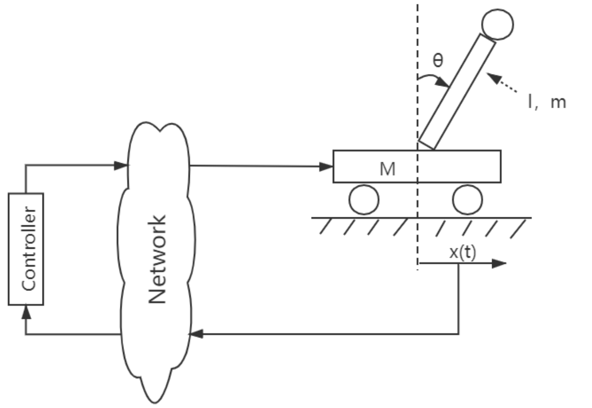

FIGURE 1. Networked pendulum control on a cart.

TABLE 2. Matrices for each case.

$Analysis$	Υ_1	Υ_2	Υ_3	Υ_4
$Case1 : H_\infty$	$-I$	0	$\gamma^2 I$	0
$Case2 : L_2 - L_\infty$	0	0	$\gamma^2 I$	$0.09I$
$Case3 : Passivity$	0	I	γI	0
$Case4 : (\mathcal{Q}, \mathcal{S}, \mathcal{R})$	$-7I$	$3I$	$I - \beta I$	0

TABLE 3. The simulation results for each case.

Case	time zone	max-$\bar{\eta}$	SP	TP	TR
1	$t \in [0, 20]$	0.49	236	36	15.3%
2	$t \in [0, 30]$	0.57	327	48	14.7%
3	$t \in [0, 50]$	0.63	510	68	13.3%
4	$t \in [0, 10]$	0.32	149	28	18.8%

points, TR is transmission rate. The corresponding feedback gain and trigger matrix in each case are received as follows:

Case 1:

$$K = \begin{bmatrix} 4.3588 & 15.6636 & 315.2232 & 176.5967 \end{bmatrix},$$
$$\Phi = \begin{bmatrix} 0.3781 & 1.2195 & 22.6974 & 12.7407 \\ 1.2195 & 4.2305 & 80.6140 & 45.2177 \\ 22.6974 & 80.6140 & 1591.4636 & 891.9445 \\ 12.7407 & 45.2177 & 0891.9445 & 499.9118 \end{bmatrix};$$

Case 2:

$$K = \begin{bmatrix} 1.5494 & 7.3968 & 237.2290 & 131.8949 \end{bmatrix},$$
$$\Phi = \begin{bmatrix} 0.0326 & 0.1386 & 4.1283 & 2.2978 \\ 0.1386 & 0.6493 & 19.5885 & 10.9010 \\ 4.1283 & 19.5885 & 618.8916 & 344.1684 \\ 2.2978 & 10.9010 & 344.1684 & 191.3966 \end{bmatrix};$$

Case 3:

$$K = \begin{bmatrix} 0.2919 & 3.1004 & 194.0046 & 107.1092 \end{bmatrix},$$
$$\Phi = \begin{bmatrix} 0.0005 & 0.0005 & 0.3291 & 0.1817 \\ 0.0053 & 0.0560 & 3.4942 & 1.9292 \\ 0.3291 & 3.4942 & 218.5644 & 120.6689 \\ 0.1817 & 1.9292 & 120.6689 & 66.6211 \end{bmatrix};$$

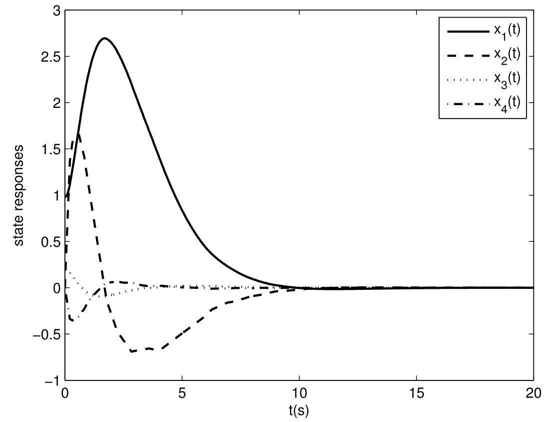

FIGURE 2. State response curves in Case 1.

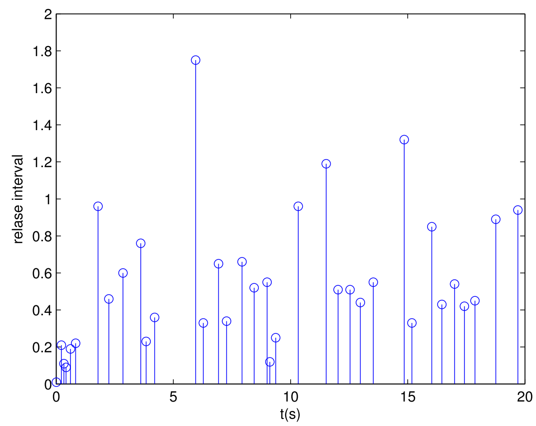

FIGURE 3. Transmission instants and release intervals in Case 1.

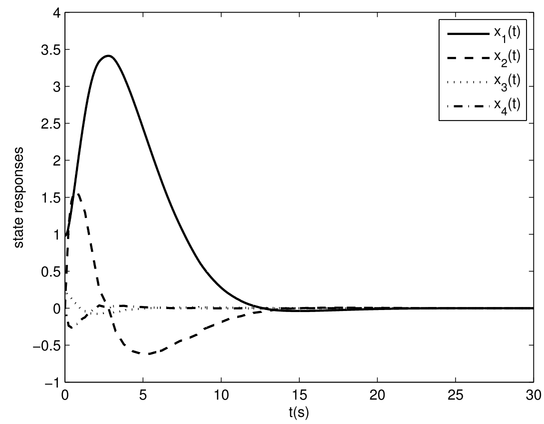

FIGURE 4. State response curves in Case 2.

Case 4:

$$K = \begin{bmatrix} 25.1830 & 62.1277 & 681.3800 & 387.7602 \end{bmatrix},$$
$$\Phi = \begin{bmatrix} 5.132 & 12.368 & 132.863 & 75.698 \\ 12.368 & 30.185 & 326.186 & 185.749 \\ 132.863 & 326.186 & 3549.454 & 2020.557 \\ 75.698 & 185.749 & 2020.557 & 1150.260 \end{bmatrix}.$$

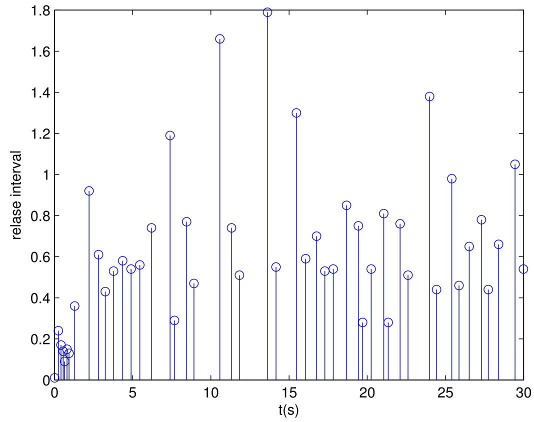

FIGURE 5. Transmission instants and release intervals in Case 2.

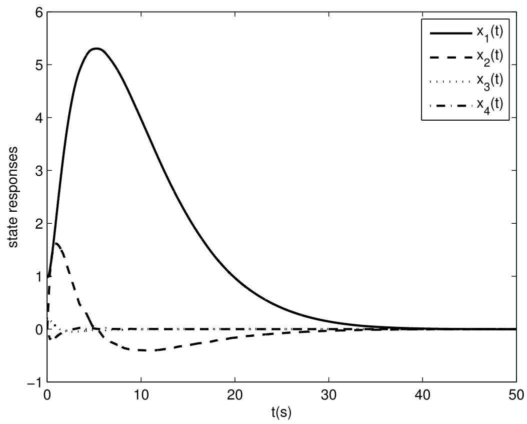

FIGURE 6. State response curves in Case 3.

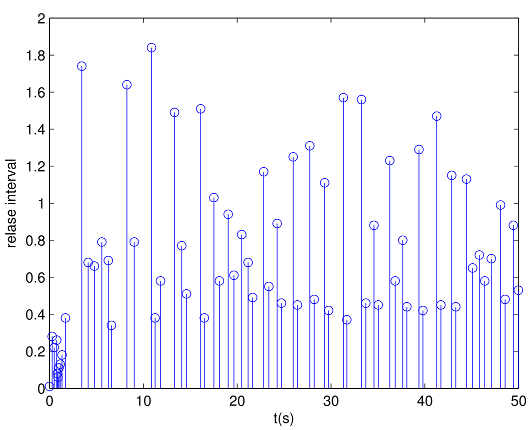

FIGURE 7. Transmission instants and release intervals in Case 3.

According to (5), the sampling period $0 < h_l \leq \bar{\eta}$. When choose $h_l \in (0, \bar{\eta}]$, the Fig.2,4,6,8 are the state response curves with K and Φ in each case. From these figures, it can be seen that the response curves gradually close to zero. It can be easily received that the designed controller with extended dissipative is effective. The Fig.3,5,7,9 show the release instants and release intervals in each case. Analysing the transfer rate in Table 3, we can see that not all signals are transmitted. The ETTS could reduce the number of transmitted points to save the communication resources.

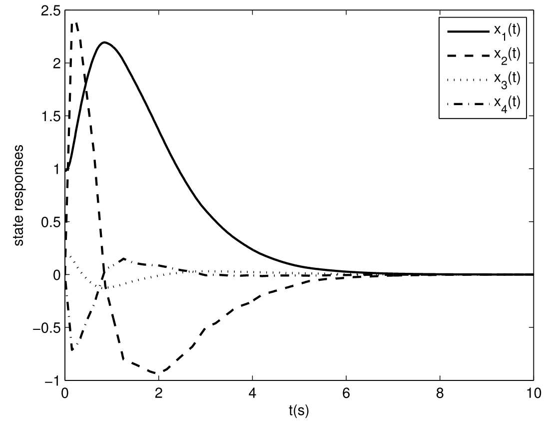

FIGURE 8. State response curves in Case 4.

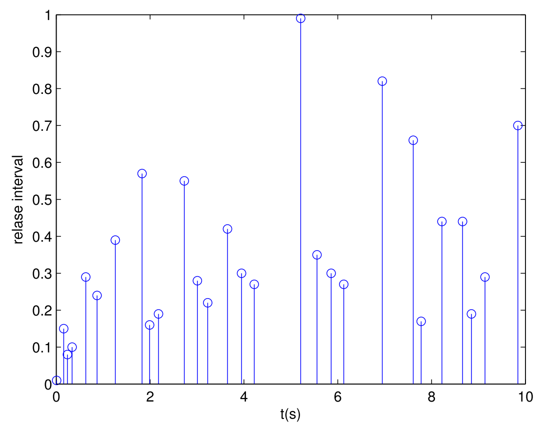

FIGURE 9. Transmission instants and release intervals in Case 4.

V. CONCLUSION

An extended dissipative control is designed with ETTS for NCSs under probabilistic cyber attacks. The extended dissipative performance is considered as follows: H_∞, $L_2 - L_\infty$, passivity and $(\mathcal{Q}, \mathcal{S}, \mathcal{R})$-dissipativity. When sampling signal is transmitted over the networks, the networks subject to probabilistic cyber attacks. The event trigger determines whether the sampled-data needs to be transmitted or not. A novel Lyapunov-Krasovskii functional which takes full characteristic of the sawtooth structure is constructed to derive the stability criterion. By utilizing the Lyapunov theory, sufficient conditions are obtained to ensure the stability with extended dissipative. Meanwhile, the feedback controller gain could be calculated. Two examples are given to prove the effectiveness of this NCSs which we designed. The obtained results are much less conservatism than the existing one. In the future, it is necessary to design a more efficient event triggering algorithms.

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LEI WANG received the M.S. degree in control science and engineering from the University of Science and Technology Beijing, Beijing, China, in 2009. Currently, she is a Lecturer with the Key Laboratory of Intelligent Motion Control System, Tangshan University, Tangshan, China. Her research interests include motion control and intelligent data information processing.

XINYUAN ZHANG received the B.S. degree from the School of Automation, City College, Hebei University of Technology, Tianjin, China, in 2019. He is currently pursing the M.S. degree in control engineering with the North China University of Science and Technology, Tangshan, China. His current research interests include fuzzy systems and event-triggered control.

CHAO GE received the M.S. degree in control theory and control engineering from the North China University of Science and Technology, Tangshan, China, in 2006, and the Ph.D. degree in control science and engineering from Yanshan University, Qinhuangdao, China, in 2015. From 2018 to 2019, he was a Postdoctoral Research Fellow at the Department of Electrical Engineering, Yeungnam University, Gyeongsan, South Korea. He is currently a Full Professor with the Institute of Electrical Engineering, North China University of Science and Technology. His research interests include event-triggered control, neural networks, fuzzy systems, and networked control systems.

RUONAN ZHANG received the M.S. degree in pediatrics from Hebei North University, Hebei, China, in 2018. She is a Pediatrician with the Shijiazhuang Maternity and Child Health Hospital. Her current research interests include pediatric digestive system diseases and the application of endoscopy in the diagnosis and treatment of pediatric diseases, event-triggered control, and neural networks.

WEN GUO received the B.S. degree from the School of Electrical Engineering and the Automatization Specialty, Tangshan College, North China University of Science and Technology, Tangshan, China, in 2020, where he is currently pursing the M.S. degree in control engineering. His current research interests include networked control systems and time-delay systems.