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A PREDICTIVE CONTROL BASED APPROACH TO NETWORKED WIENER SYSTEMS

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Abstract. *A predictive control based approach is proposed to deal with a Wiener type system which is closed through a network. In this approach, an output feedback predictive controller is designed using delayed sensing data with a specially designed state observer. The network constraints, i.e., the network-induced delay and data packet dropout, are compensated in both the forward and backward channels by taking advantage of the characteristics of both the predictive controller and the network transmission. Stability of the closed-loop system is derived by using the separation principle and switched system theory. Simulations illustrate the validity of the proposed approach.*
Keywords: Networked control systems, Predictive control, Wiener system, Network constraints

1. **Introduction.** Networked Control Systems (NCSs) is an emerging research area in recent years. Distinct from conventional control systems, where the links from sensor to controller ("backward channel") and from controller to actuator ("forward channel") are assumed to be connected directly with no data loss or delay through the links, in NCSs, instantaneous and perfect signals between these components are not achievable due to the inserted network [12, 14]. Despite the ability of remote and distribute control that such a configuration brings, the network constraints, i.e., the network-induced delays, data packet dropout, communication bandwidth limitation, data rate constraints, etc. in NCSs present a new challenge to conventional control theory [5, 2, 10, 6, 13].

A challenging aspect of the networked configuration is that we need to compensate for the negative effects of the network constraints to retain stability and performance of the system. For this purpose, a natural and necessary approach is to take advantage of all the information available on the network to design the controller rather than separate the design of the controller and network protocols. Preliminary work on this can be found in a number of publications under the name of "co-design" [3, 15, 16]. Following this idea, a model based control architecture was proposed in [9], where the knowledge of the plant dynamics was used to reduce the usage of the network. Furthermore, a predictive control based control architecture was also reported recently in [4, 8, 16]. In [8], knowledge of the plant dynamics was used to produce future control signals to actively compensate for the random network-induced delay in the forward channel with the use of a corresponding time delay compensator at the actuator side. A better performance can be expected since the predictive control based approach takes greater advantage of the knowledge available. However, only few results on nonlinear NCSs have been reported to date under such a predictive control based framework [11].

In this paper, a modified predictive control based approach is applied to a Wiener type system with network constraints [1, 7]. For the output nonlinearity in the Wiener type system, an output feedback predictive controller is obtained using delayed sensing data with the help of a specially designed state observer. Unlike normal predictive control applications, where only the first predictive input of the predictive control sequence is applied to the plant, in this paper, the whole predictive control sequence is packed and sent to the actuator through the network and the appropriate predictive input is chosen by the actuator by a certain rule. With this modification, the conventional predictive control method can readily extend its application to the networked control environment, where the network-induced delay and data packet dropout are exactly compensated for. The stability of the closed-loop system is obtained by proving the stability of the proposed state observer under certain conditions and modeling the closed-loop system as a switched system.

The remainder of the paper is organized as follows. Section 2 presents the design details of the proposed predictive based approach to Wiener systems with network constraints; Section 3 analyzes the stability of the closed-loop system; Section 4 gives a simple example to illustrate the validity of the proposed approach and Section 5 concludes the paper.

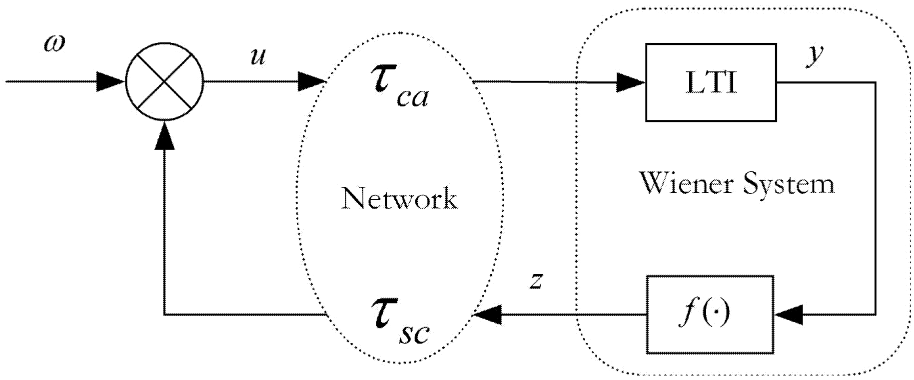

FIGURE 1. Wiener systems closed through networks

2. **Design of the Predictive Control Based Approach to Wiener Systems with network constraints.** We consider the following Single-Input-Single-Output (SISO) Wiener type system which is closed through some form of network (Figure 1) in this paper,

$$x(k+1) = Ax(k) + bu(k) \tag{1}$$
$$y(k) = cx(k) \tag{2}$$
$$z(k) = f(y(k)) \tag{3}$$

where $x \in \mathbb{R}^n$, $u, y, z \in \mathbb{R}$, $A \in \mathbb{R}^{n\times n}$, $b \in \mathbb{R}^{n\times 1}$, $c \in \mathbb{R}^{1\times n}$. The memoryless static nonlinear function $f(\cdot)$ is assumed to be invertible with its inverse denoted by $\hat{f}^{-1}(\cdot)$. Notice that $\hat{f}^{-1}(\cdot)$ can not be obtained accurately in practice which means $\varphi(\cdot) = \hat{f}^{-1}(f(\cdot)) \not\equiv 1(\cdot)$. The approximate intermediate output $\tilde{y}(k)$ (Figure 2) can thus be obtained as follows,

$$\tilde{y}(k) = \hat{f}^{-1}(z(k)) = \varphi(y(k)) \tag{4}$$

With this inverse process, the predictive controller for the system in (1)–(3) in a networked environment can then be obtained using a Linear Generalized Predictive Control (LGPC) method and a state observer as follows.

2.1. **Design of the predictive controller using delayed data.** Let the cost function be defined by

$$J(N_1,N_2,N_u)=\sum_{j=N_1}^{N_2} q_j(\hat{y}(k+j|k-\tau_{sc,k})-\omega(y;k+j))^2+\sum_{j=1}^{N_u} r_j\Delta u^2(k+j-1) \quad (5)$$

where N_1 and N_2 are the minimum and maximum prediction horizons, N_u is the control horizon, $q_j, N_1 \le j \le N_2$ and $r_j, 1 \le j \le N_u$ are weighting factors, $\Delta u(k)=u(k)-u(k-1)$ is the control increment, $\hat{y}(k+j|k-\tau_{sc,k}), j=N_1,...,N_2$ are the forward predictions of the system outputs, which are obtained on data up to time $k-\tau_{sc,k}$, where $\tau_{sc,k}$ is the network-induced delay in the backward channel at time k; $\omega(y;k+j)$ is the set point with respect to y and can be obtained approximately by inverting corresponding set point $\omega(z;k+j)$ with respect to z, i.e.,

$$\omega(y;k+j)=\hat{f}^{-1}(\omega(z;k+j)), j=N_1,...,N_2 \quad (6)$$

Let $\bar{x}(k)=[x^T(k)\ u(k-1)]^T$, then the system in (1)–(3) can be rewritten as follows,

$$\bar{x}(k+1)=\bar{A}\bar{x}(k)+\bar{b}\Delta u(k) \quad (7)$$

$$y(k)=\bar{c}\bar{x}(k) \quad (8)$$

where $\bar{A}=\begin{pmatrix} A & b \\ 0 & 1\end{pmatrix}$, $\bar{b}=\begin{pmatrix} b \\ 1\end{pmatrix}$, $\bar{c}=\begin{pmatrix} c & 0\end{pmatrix}$. Thus the j' step forward output prediction at time k' is

$$\hat{y}(k'+j'|k')=\bar{c}\bar{A}^{j'}\bar{x}(k')+\sum_{l'=0}^{j'-1}\bar{c}\bar{A}^{j'-l'-1}\bar{b}\Delta u(k'+l')$$

Let $j'=j+\tau_{sc,k}$, $k'=k-\tau_{sc,k}$, $l'=l+\tau_{sc,k}$, then the forward output predictions at time k based on the information of the state on time $k-\tau_{sc,k}$ and control signals from time $k-\tau_{sc,k}-1$ is

$$\hat{y}(k+j|k-\tau_{sc,k})=\bar{c}\bar{A}^{j+\tau_{sc,k}}\bar{x}(k-\tau_{sc,k})+\sum_{l=-\tau_{sc,k}}^{j-1}\bar{c}\bar{A}^{j-l-1}\bar{b}\Delta u(k+l) \quad (9)$$

Let $\hat{Y}(k|k-\tau_{sc,k})=[\hat{y}(k+N_1|k-\tau_{sc,k})\ \cdots\ \hat{y}(k+N_2|k-\tau_{sc,k})]^T$, $\Delta U'(k|k-\tau_{sc,k})=[\Delta u(k-\tau_{sc,k}|k-\tau_{sc,k})\ \cdots\ \Delta u(k+N_u-1|k-\tau_{sc,k})]^T$, then

$$\hat{Y}(k|k-\tau_{sc,k})=E_{\tau_{sc,k}}\bar{x}(k-\tau_{sc,k})+F_{\tau_{sc,k}}\Delta U'(k|k-\tau_{sc,k}) \quad (10)$$

where $E_{\tau_{sc,k}}=[(\bar{c}\bar{A}^{N_1+\tau_{sc,k}})^T\ \cdots\ (\bar{c}\bar{A}^{N_2+\tau_{sc,k}})^T]^T$, $F_{\tau_{sc,k}}$ is a $(N_2-N_1+1)\times(N_u+\tau_{sc,k})$ matrix with the non-null entries defined by $(F_{\tau_{sc,k}})_{ij}=\bar{c}\bar{A}^{N_1+\tau_{sc,k}+i-j-1}\bar{b}, j-i\le N_1+\tau_{sc,k}-1$. Note here that $E_{\tau_{sc,k}}$ and $F_{\tau_{sc,k}}$ vary with different $\tau_{sc,k}$s.

Let $\varpi_k(y;\cdot)=[\omega(y;k+N_1)\ \cdots\ \omega(y;k+N_2)]^T$, the optimal predictive control increments from k to $k+N_u-1$ can then be calculated by letting $\partial J(\cdot)/\partial\Delta U'=0$,

$$\Delta U(k|k-\tau_{sc,k})=M_{\tau_{sc,k}}(\varpi_k(y;\cdot)-E_{\tau_{sc,k}}\bar{x}(k-\tau_{sc,k})) \quad (11)$$

where $\Delta U(k|k-\tau_{sc,k})=[\Delta u(k|k-\tau_{sc,k})\ \cdots\ \Delta u(k+N_u-1|k-\tau_{sc,k})]^T$, $M_{\tau_{sc,k}}=H_{\tau_{sc,k}}(F^T_{\tau_{sc,k}}QF_{\tau_{sc,k}}+R)^{-1}F^T_{\tau_{sc,k}}Q$, Q, R are diagonal matrices with $Q_{i,i}=q_i, R_{i,i}=r_i$ respectively and $H_{\tau_{sc,k}}=[0_{N_u\times\tau_{sc,k}}\ I_{N_u\times N_u}]$, $I_{N_u\times N_u}$ is the identity matrix with rank N_u.

Since the system states are normally unavailable for the controller, we construct the following system:

$$\hat{x}(k+1) = A\hat{x}(k) + bu(k) \tag{12}$$
$$\hat{y}(k) = \varphi(c\hat{x}(k)) \tag{13}$$

to observe the system states,

$$\hat{x}(k+1) = A\hat{x}(k) + bu(k) + L(\tilde{y}(k) - \hat{y}(k)) \tag{14}$$

where $\hat{x}(k)$ is the observed state at time k.

Let $\hat{\bar{x}}(k) = [\hat{x}(k)\ u(k-1)]$, the real predictive control sequence can then be obtained as

$$\Delta U(k|k-\tau_{sc,k}) = M_{\tau_{sc,k}}(\varpi_k(y;\cdot) - E_{\tau_{sc,k}}\hat{\bar{x}}(k-\tau_{sc,k})) \tag{15}$$

Remark 2.1. *Notice that the calculation of the predictive control sequence $\Delta U(k|k-\tau_{sc,k})$ in (15) is only based on the input and output data up to time $k-\tau_{sc,k}-1$. This can be compared with the one applied in* [8] *where the data from time $k-\tau_{sc,k}$ to $k-1$ are used to determine the predictive controller, which certainly is hard to obtain by the controller in practice.*

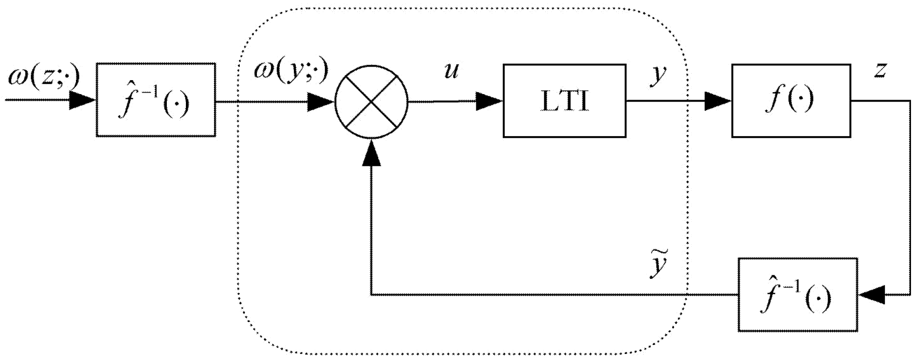

FIGURE 2. Predictive based approach to ~~wiener~~ systems

2.2. **Design of the compensation scheme for network constraints.** To take advantage of the characteristics of the network transmission and the predictive controller to compensate for the network constraints, i.e., network-induced delays and data packet dropout, the following assumptions are made:

A1. A time stamp can be used for each data packet transmitted through the network to notify the time when it was sent;

A2. The sum of the maximum network-induced delay in the forward channel (denoted by $\bar{\tau}_{ca}$) and the maximum number of continuous data packet dropout (denoted by $\bar{\chi}$) is bounded by the control horizon, i.e.,

$$\bar{\tau}_{ca} + \bar{\chi} \le N_u - 1 \tag{16}$$

A3. Each control predictive sequence $U(k|k-\tau_{sc,k})$ is packed into one packet to be sent to the actuator.

Remark 2.2. *The network-induced delay in the backward channel for each data packet is known to the controller under assumption A1.*

Remark 2.3. *The network-induced delays in both channels for each control predictive sequence are known to the actuator under assumptions A1 and A3.*

Note here that different from conventional predictive control implementations, where only the first predictive input is applied to the plant, in this paper, we generate a sequence of predictive inputs and send them in one data packet to the actuator. This is the key point of the proposed approach to compensate for the network constraints.

With the assumptions above, we propose the following schemes to compensate for the network constraints in the backward and forward channels, respectively.

2.2.1. *Compensation for the network constraints in the backward channel.* From Remark 2.1 we know that the network-induced delay in the backward channel is known to the controller, which enables the predictive control sequence to be calculated (see equation (15)). However, as the matrices $E_{\tau_{sc,k}}$, $F_{\tau_{sc,k}}$, $M_{\tau_{sc,k}}$, $H_{\tau_{sc,k}}$ in (15) vary with the network-induced delay in the backward channel, it would be a great computation burden for the predictive controller if these matrices are calculated online. Fortunately, these matrices, actually, can be calculated off line since all the matrices are fixed for a given τ_{sc}. This advantage enables us to calculate off line all the matrices with respect to the specific τ_{sc}s, store them in the controller and just choose the appropriate ones when calculating online the predictive control increments, according to the current value of the delay $\tau_{sc,k}$.

2.2.2. *Compensation for the network constraints in the forward channel.* In order to implement the compensation scheme to compensate for the network constraints in the forward channel, we introduce a cache for the actuator. When a new sequence arrives at the actuator side in one data packet as given in assumption A3, it is compared with the one already in the cache of the actuator according to the time stamps and only the latest one sent from the controller is stored. The cache is specially designed for the actuator and it can only store one control sequence (data packet) at any one time.

The comparison process is introduced at the actuator side due to the fact that different data packets may experience different delays in the forward channel, thereby producing a situation where for example a data packet sent earlier from the controller may arrive at the actuator later or may never arrive in the case of data packet dropout. As a result of the comparison process, the predictive control sequence stored in the cache of the actuator is always the latest one available at any specific time.

At every execution time instant, the actuator picks out the appropriate control signal which can compensate for the current network-induced delay in the forward channel from the predictive control sequence and applies it to the plant. The method used to choose the appropriate control increment signal at a specific time will be further explained in the next section. It is necessary to point out that the appropriate control increment is always available using the delay compensator if assumption A2 holds.

The algorithm of the predictive control based approach to Wiener systems with compensation for network constraints can now be summarized as follows:

- S1. The predictive controller receives the delayed signals of output $z(k-\tau_{sc,})$ and control input $\Delta u(k-\tau_{sc,k})$ and reads the current network-induced delay in the backward channel $\tau_{sc,k}$;
- S2. The predictive controller calculates the predictive control sequence $\Delta U(k|k-\tau_{sc,k})$ through (15) using delayed data;
- S3. The predictive control sequence $\Delta U(k|k-\tau_{sc,k})$ is packed and sent to the actuator simultaneously with time stamps k and $\tau_{sc,k}$;
- S4. The cache of the actuator updates its predictive control sequence according to the time stamps once a data packet arrives;

S5. An appropriate control increment signal is picked out from the predictive control sequence and applied to the plant.

The structure of the proposed approach is illustrated in Figure 3.

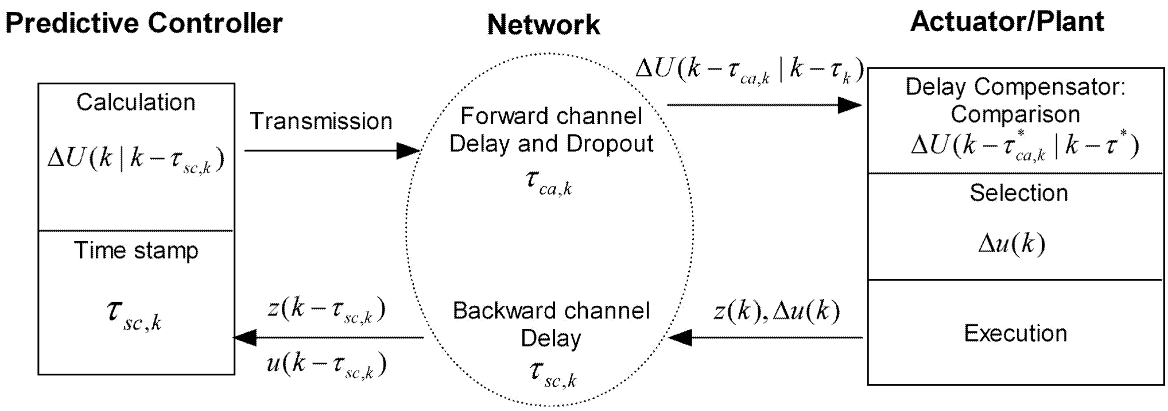

FIGURE 3. The structure of networked predictive control system

3. Stability of the proposed approach.

In this section, we first prove that the state observer proposed in this paper is stable under certain conditions. This fact enables us to construct the stability theorem for the closed loop system.

3.1. Observer error.

Let the observer error $e(k) = x(k) - \hat{x}(k)$. From equations (1), (12) we obtain

$$\begin{aligned} e(k+1) &= x(k+1) - \hat{x}(k+1) \\ &= Ae(k) - L(\tilde{y}(k) - \hat{y}(k)) \end{aligned} \tag{17}$$

Assume $\varphi(\cdot) \in C^1$, then by mean value theorem,

$$\begin{aligned} \tilde{y}(k) - \hat{y}(k) &= \varphi(cx(k)) - \varphi(c\hat{x}(k)) \\ &= c\varphi'(\xi_k))e(k) \end{aligned} \tag{18}$$

where $\xi_k \in [\min\{cx(k), c\hat{x}(k)\} \;\; \max\{cx(k), c\hat{x}(k)\}]$.

Combining equations (17) and (18) yields

$$e(k+1) = (A - Lc\varphi'(\xi_k))e(k) \tag{19}$$

Notice that though $\varphi(\cdot) \not\equiv 1(\cdot)$, it is reasonable to assume that the compensation for the nonlinear function $f(\cdot)$ is smooth, which means there exists $\varepsilon > 0$ s.t. $|\varphi'(\alpha) - 1| \leq \varepsilon, \forall \alpha \in \mathbb{R}$. Thus the dynamics of the observer error can be obtained as

$$\begin{aligned} e(k+1) =&(A - Lc - \zeta_k Lc)e(k) \\ =&A_{\zeta_k} e(k) \end{aligned} \tag{20}$$

where $A_{\zeta_k} = A - Lc - \zeta_k Lc$, $|\zeta_k| \leq \varepsilon$.

Theorem 3.1 (Observer Error). *The observer error converges to 0 if there exists a positive definite solution $P_e = P_e^T > 0$ to the following two LMIs*

$$\begin{aligned} A_\varepsilon^T P_e A_\varepsilon - P_e \leq 0 \\ A_{-\varepsilon}^T P_e A_{-\varepsilon} - P_e \leq 0 \end{aligned} \tag{21}$$

where $A_\varepsilon = A - Lc - \varepsilon Lc$ and $A_{-\varepsilon} = A - Lc + \varepsilon Lc$.

Proof: Let $V(k) = e^T(k)P_e e(k)$ be a Lyapunov function candidate. Notice the fact that for any ζ_k, there exists $0 \le \lambda_k \le 1$ such that $\zeta_k = \lambda_k\varepsilon + (1-\lambda_k)(-\varepsilon)$. Thus by simple calculation, the incremental V for system (20) can be obtained as

$$\begin{aligned}\Delta V(k+1) =& e^T(k)\Gamma_{\zeta_k} e(k)\\ =& e^T(k)(\lambda_k\Gamma_\varepsilon + (1-\lambda_k)\Gamma_{-\varepsilon} - 4\lambda_k(1-\lambda_k)(Lc)^T P_e Lc)e(k)\end{aligned} \tag{22}$$

where $\Gamma_{\zeta_k} = A^T_{\zeta_k} P_e A_{\zeta_k} - P_e$.

Noticing that $\lambda_k(1-\lambda_k) \ge 0$ and $(Lc)^T P_e Lc$ is semi positive definite, it yields that $\Delta V(k)$ is decreasing which completes the proof.

3.2. **Closed-loop stability.** Let $\tau^*_{ca,k}$ denote the network-induced delay in the forward channel of the predictive control sequence, from which the control signal is picked out by the actuator at time instant k. The time when the sequence was sent from the controller can then be read from its time stamp as

$$k^* = k - \tau^*_{ca,k} = \max_j\{j|\Delta U(j|j-\tau_{sc,j}) \in \Gamma_k\} \tag{23}$$

where Γ_k is the set of the predictive control increment sequences that are available during time interval $(k-1,k]$ at the actuator side, including not only the one in the cache of the actuator but others that arrive at the actuator during this interval.

From equations (15), (23), the control signal adopted by the actuator at time k is obtained as

$$\begin{aligned}\Delta u(k) &= d^T_{\tau^*_{ca,k}}\Delta U(k-\tau^*_{ca,k}|k-\tau^*_k)\\ &= -d^T_{\tau^*_{ca,k}} M_{\tau^*_k} E_{\tau^*_k}\hat{\bar{x}}(k-\tau^*_k)\\ &= -\Sigma_{\tau_k}\hat{\bar{x}}(k-\tau^*_k)\end{aligned} \tag{24}$$

where $d_{\tau^*_{ca,k}}$ is a $N_u \times 1$ matrix with all entries 0 except the $(\tau^*_{ca,k}+1)$th is 1, $\tau^*_k = \tau^*_{ca,k} + \tau^*_{sc,k}$, $\tau^*_{sc,k} = \tau_{sc,k^*}$, $\Sigma_{\tau_k} = d^T_{\tau^*_{ca,k}} M_{\tau^*_k} E_{\tau^*_k}$ and the set point is assumed to be 0 without loss of generality.

Let $\bar{e}(k) = \bar{x}(k) - \hat{\bar{x}}(k) = [e(k)\ 0]^T$, then

$$\bar{e}(k+1) = \bar{A}_{\xi_k}\bar{e}(k) \tag{25}$$

where $\bar{A}_{\xi_k} = \begin{pmatrix} A - Lc\varphi'(\xi_k) & 0 \\ 0 & 0 \end{pmatrix}$.

Let $Z(k) = [\bar{x}^T(k-\bar{\tau})\ \cdots\ \bar{x}^T(k)\ \bar{e}(k-\bar{\tau})\ \cdots\ \bar{e}(k)]^T$, then the closed loop system can be represented by

$$Z(k+1) = \Lambda_{\xi_k,\tau_k} Z(k) \tag{26}$$

where $\Lambda_{\xi_k,\tau_k} = \begin{pmatrix} \Lambda^{11}_{\tau_k} & \Lambda^{12}_{\tau_k} \\ 0 & \Lambda^{22}_{\xi_k} \end{pmatrix}$, $\Lambda^{11}_{\tau_k} = \begin{pmatrix} 0_{n+1} & I_{n+1} & & & \\ & & I_{n+1} & & \\ & & & \ddots & \\ & & & & I_{n+1} \\ \cdots & -\Sigma_{\tau_k} & \cdots & & \bar{A} \end{pmatrix}$,

$\Lambda_{\xi_k}^{22} = \begin{pmatrix} 0_{n+1} & I_{n+1} & & & \\ & 0_{n+1} & I_{n+1} & & \\ & & \ddots & \ddots & \\ & & & \ddots & I_{n+1} \\ & & & & \bar{A}_{\xi_k} \end{pmatrix}$, and $\Lambda_{\tau_k}^{12}$ is a block matrix with all its entries (blocks) 0 except $(\Lambda_{\tau_k}^{12})_{(\bar{\tau}-1)\times(\bar{\tau}-\tau_k^*+1)} = -\Sigma_{\tau_k}$.

Theorem 3.2 (Closed-loop stability)**.** *The closed loop system is stable if (21) holds and there exists a positive definite solution $P_c = P_c^T > 0$ for the following $(\bar{\tau}_{ca}+1)(\bar{\tau}_{sc}+1)$ LMIs*

$$(\Lambda_{\tau_k}^{11})^T P_c \Lambda_{\tau_k}^{11} - P_c \leq 0 \tag{27}$$

Proof: Noticing the block-triangular structure of the system matrix Λ_{ξ_k,τ_k} for the closed-loop system, we see that the state observer can be designed separately without influencing the stability of the system and the closed-loop system is stable if we can guarantee the stability of the state observer (Theorem 3.1) and the following system,

$$X(k+1) = \Lambda_{\tau_k}^{11} X(k) \tag{28}$$

where $X(k) = [\bar{x}^T(k-\bar{\tau}) \ \cdots \ \bar{x}^T(k)]$.

Let $V(k) = X^T(k) P_c X(k)$ be a Lyapunov function candidate, then the incremental $V(k)$ for system (28) is

$$\Delta V(k) = X^T(k)((\Lambda_{\tau_k}^{11})^T P_c \Lambda_{\tau_k}^{11} - P_c)X(k)$$

which completes the proof using equation (27).

Remark 3.1. *Notice that the two conditions ((21) and (27)) that guarantee the stability of the closed-loop system are with respect to the compensation accuracy for the nonlinearity and the influence of the network constraints respectively.*

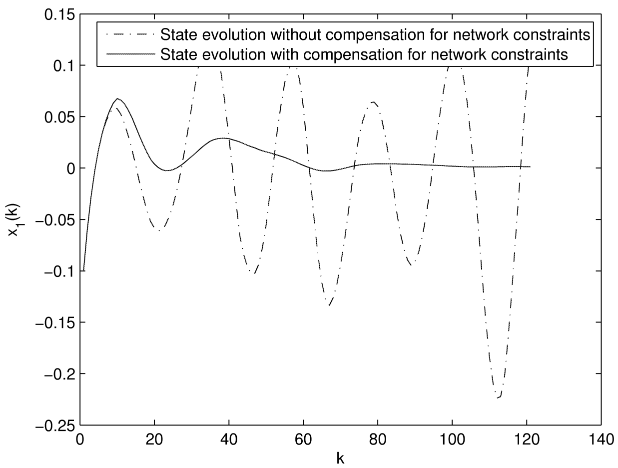

FIGURE 4. A comparison between with/without compensation for network constraints

4. **Simulation.** An example is given in this section to illustrate the validity of the proposed approach. For this purpose, a second order plant model in discrete time with a

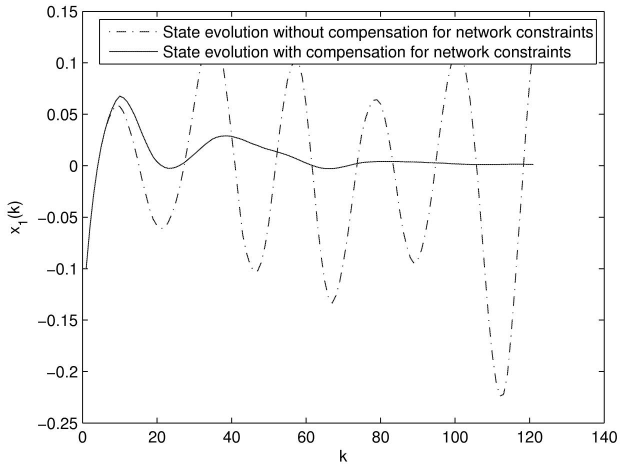

FIGURE 5. A comparison between with/without compensation for output nonlinearity

static nonlinear output process and random delays in both channels and data packet dropout in the forward channel, is adopted,

$$A = \begin{pmatrix} 0.8 & 0.1 \\ 0 & 1 \end{pmatrix}, b = \begin{pmatrix} 0.05 \\ 0.2 \end{pmatrix}, c = \begin{pmatrix} 1 & 0 \end{pmatrix}.$$

Other parameters of the simulation are chosen as $\bar{\tau} = 8, \bar{\tau}_{ca} = 4, \bar{\tau}_{sc} + \bar{\chi} = 4, N_u = 8, N_p = 10, \varepsilon = 0.5$ and the initial state $x(0) = x_0 = [-0.1\ 0.2]^T$. The delays in both channels are set to vary randomly within their upper bounds. Such a system using the proposed approach in this paper can be proven to be stable under Theorem 3.2.

Two cases which illustrate the validity of the compensation for the network constraints and the compensation for the output nonlinearity respectively, are shown in Figure 4 and Figure 5. In both cases, all the other parameters remain the same and only the evolution of the first state of the system is illustrated. The simulation results show that the system is stable with the compensation scheme while unstable without it, which illustrate the validity of the proposed approach in this paper.

5. **Conclusion.** In this paper, we propose a predictive control based approach to deal with a Wiener type system which is closed through a network. In this approach, a state observer is designed to derive the predictive controller using delayed sensing data, and with the use of time stamps for each data packet, the negative effects of the network-induced delay and data packet dropout in both channels are also compensated for. The deriving closed-loop system is proved to be stable under certain conditions related to the compensation for the nonlinear process and the network constraints. The effects of the compensation for the nonlinearity and network constraints are also illustrated by simulations.

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