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# A Survey - Networked Control Systems

**B Sharmila and Dr. N. Devarajan**

*Assistant Professor, Department of EIE,*
*Sri Ramakrishna Engineering College, Coimbatore, Tamilnadu, India*
*sharmi.rajesh@gmail.com*
*Professor & Head, Department of EEE,*
*Government College of Technology, Coimbatore, Tamilnadu, India*

**Abstract**

The use of a data network in a control loop has gained increasing attentions in recent years due to its cost effective and flexible applications. The major challenges in this so-called Networked Control System (NCS) are the network-induced delay and packet losses in the control loop. These challenges degrade the NCS control performance and destabilize the system. A significant emphasis has been on developing control methodologies to handle these problems in NCS. This survey paper presents recent NCS control techniques and also provides an overview on NCS structures and description of network delays including characteristics and effects are also covered.

**Keywords:** Networked Control Systems (NCS}; Network Challenges – Delay and Packet Losses; A Survey.

## Introduction

During the past decades, the Networked Control System (NCS) in industry has made great advances. The exchange of information by adapting communication network with a closed control loop is called as Networked Control System. Due to the advantages of high control utilization, simple installation and great flexibility and low cost, NCS have been significantly attracted research communities with important results for the updation of the literature. NCS faced challenges as networked induced delay and packet dropouts which degrades and destabilized the system performance. Numerous control methods such as fuzzy control, neural control, adaptive control, nonlinear control and optimal control techniques and many more techniques are discussed in this paper.

## NCS Configuration

There are two general NCS configurations as Direct and Hierarchical Structures. In Hierarchical Structure approach Fig. 1 the plant is controlled by its own remote controller at remote station. The central controller provides the set point to the plant via remote controller and the sensor measurements of the system are sent from the remote station to central controller. The set points and sensor measurements are transmitted through network. This approach has a poor interaction between the central and remote unit because of not transmitting the control signal from central controller. The direct structure Fig. 2 approach uses the network for the direct transfer of the control signal and the sensor measurements between a remote unit and a central controller. The central controller is connected to the plant through an interface unit. The control and analysis methodologies for the direct structure could also be applied for the hierarchical structure by treating the remote closed-loop system as a pure plant. In this case, the remote closed-loop system is represented by a state-space model or a transfer function similar to the plant.

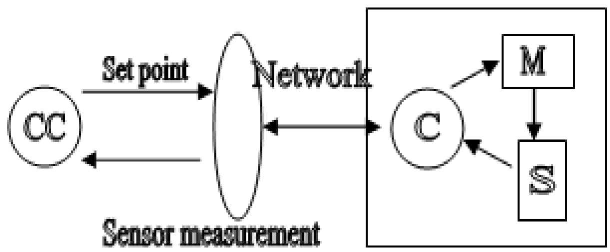


**Figure 1.** NCS in the Hierarchical Structure.

## Overview on networked control systems

A networked control system can be divided into the remote unit, the central controller and the data network. In order to focus our discussion on the performance of networked closed loop control system with network conditions (delay, data loss), a networked control system plant has been illustrated. Fig. 1 shows the general block diagram of the networked control system under investigation.

### Remote Unit

The Remote Unit consists of the plant, sensor and an interfacing unit. Via the network the remote unit can receive control signal from central controller and also send measurements back to the central controller.

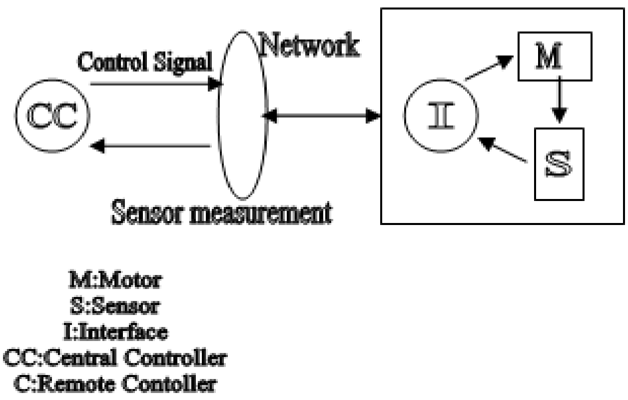


**Figure 2.** NCS in the Direct Structure.

**Central Controller**

The central controller will provide the control signal $u_C(t)$ to the remote systems as in Fig. 3. The central controller will monitor the network conditions of the remote unit link and provide appropriate control signals to the remote unit. Similarly the output responses are taken as feedback signal $y_R(t)$ to the central controller. The controller will compensate the network-induced delays, data losses and external disturbances. The data losses and disturbances occur due to missing or disturbances in input reference signal, control signal and feedback signal.

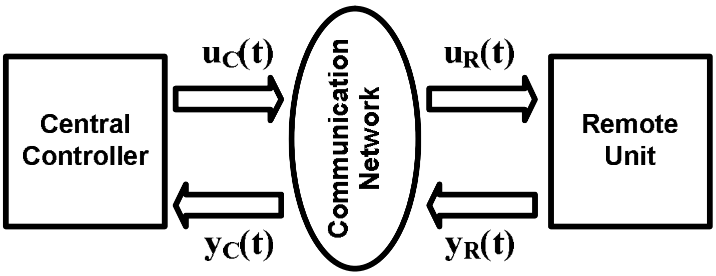


**Figure 3.** General NCS configuration and network delays for NCS formulations.

**Data Networks**

There are different ways to define network conditions for point-to-point configuration (from the central control to a specific remote unit and vice versa). Two of the most popular network measures are the point-to-point network throughput, maximal delay bound of the largest data and the sampling time. At each time instant, the packet in the network contains either the plant information to the controller or control signal to plant. In the network, network-induced delay and packet dropout occur. Once the packet is delayed in the network, then packet dropout automatically occurs in the system. To keep the illustration simple, the remote unit receives the data sent from the central controller as $u_R(t)$, which can be mathematically expressed as

$$u_R(t) = u_C(t - \tau_R) \tag{1}$$

where $\tau_R$ is the time delay to transmit the control signal $u_C(t)$ from the central controller to the remote unit. The remote unit also sends the sensors signals $y_R(t)$ of the remote system back to the central controller $y_C(t)$, and these two signals are related a

$$y_C(t) = y_R(t - \tau_C) \tag{2}$$

where $\tau_C$ is the time delay to transmit the measured signal from the remote unit to the central controller. The functions of network variables such as the packet dropouts, network throughput, the network management/policy used, the type and number of signals to be transmitted, the network protocol used, and the controller processing time, and the network traffic congestion condition are taken as the current network conditions n(t) and let $z^{-t}$ be a time delay operator which defines the signals as

$$u_R(t) = u_c(z^{-t_R}, n(t)) \tag{3}$$

$$y_c(t) = y_R(z^{-t_c}, n(t)) \tag{4}$$

There are also processing delays as $\tau_{PC}$ and $\tau_{PR}$, at the central and remote unit, respectively which could be approximate small constants or even neglected because these delays are usually small compared to $\tau_C$ and $\tau_R$.

## Control Techniques – a survey

In [1] – [2] a detailed survey of the state of the art of NCS are provided. The important problems of the real time data mining that are associated with large scale, the spatially distributed arrays of RF networked sensors, the real time data fission for heterogeneous and distributed arrays of sensors and distributed control and the communication for peer to peer network to manage device node drop-outs and network reconfiguration strategies among others are discussed. In [3] a NCS model containing a clock driven sensors and event-driven controller and actuators are studied with comparison of both timings. The relationship between the sampling rate and network induced delay were analyzed using stability region plot and using hybrid systems technique the NCS stability was analyzed.

Fuzzy Modulated PID controller are discussed in [4], [8], [10] and [12]. [4] proposes the use of the fuzzy logic concept to modulate the system control gain of the PI controller for compensating the time delay problems in the network based controlled dc motor. For the compensation and improvement in the performance of the PI control under difference network delays & bandwidth the author has introduced a parameter β to the existing PI controllers control signal such that new control signal will be provided by the central controller. (where β is a nonlinear function that discrete the input /output relation of the fuzzy compensator)

PID controller was used in [5] - [6]. In [5] PID controller was used for networked DC motor control with network-induced delay. And in [6] NCS for motor speed control was implemented by using a Profibus –DP Network for the performance evaluation and also the author proposed a modified traditional design method for PID controller to minimize the effects of network delays on the system. Ziegler – Nichols method & Cohen Coon method were used to design the PID controllers with network and without network are compared in terms of maximum overshoots and settling time.

The survey on control methodologies for NCS was provided in [8] and [53]. In [8] the author provided a survey on the control methodologies for networked induced delays as augumented deterministic discrete time model methodology, queuing method, optimal stochastic control method, perturbation method, sampling time scheduling method, robust control method, fuzzy logic modulation, event based method and end user control adaptation method for a closed loop control system over a data network with different applications and the paper also provided the NCS configuration, network delay characteristics and effects due to network delays.

Tipsuwan and Chow in [9] presented a gain scheduling approach for network traffic condition and enhanced the existing PI controllers for using over IP network. In part I [11] a partial adaptation scheme to tune the consequent parameters for the fuzzy logic modulator was presented and numerical simulation of a network-based controlled DC motor is used to illustrate the effectiveness of the proposed scheme over a direct PI controller parameter tuning. And in part II [10] the full adaptive fuzzy modulation (AFM), where both consequent parameters and membership functions parameters are tuned adaptively for further improvement in the performance of the system.

Yong-Can Cao and Wei-dong Zhang [12] presented the classic PID controller for network delays in Networked Control Systems by adding the modified fuzzy controller which can dynamically adapt the change of delays because of the adaptation of the fuzzy logic. [7], [13] - [14], [20], [23], [37] - [38], [56] - [58] introduces fuzzy logic controller in control system. In [7] Remote Fuzzy Logic Control for servo motor control via Profibus-DP was proposed and compared it with the PID controller for compensation of network-induced delays. A self tuning Fuzzy Controller with first and second level controllers was designed [14] by the author to control a NCS with the presence of delay and packet losses. [13], [23] and [58] used Takagi-Sugeno (T-S) based fuzzy model in NCS for network induced delays and data packet loss challenges. The fuzzy H∞ control scheme [20] for a class of NCS for both network-induced delay and packet dropout via the Fuzzy Estimator has been proposed via limited sampling information. The H∞ T-S fuzzy control problem for systems with repeated scalar nonlinearities and random packet losses was investigated in [38] and in [37] T-S fuzzy model was used to model the nonlinear plant, and the communication link failure was modeled via a stochastic variable satisfying the Bernoulli random binary distribution.

In [15] the authors designed in the presence of random packet losses with an observer based feedback controller which robustly exponentially stabilizes the networked system in the sense of mean square and also achieved the prescribed H∞ disturbance-rejection-attenuation level. The controller design problem was solvable by making Linear Matrix Inequalities (LMI) feasible. Gao and Chen in [16] used a robust H∞ filter design case having degrees of conservativeness and computational complexity for illustrating the network having limited communication capacity as measurement quantization, signal transmission delay, and data packet dropout. A LMI based conditions was formulated for the existence of admissible filter which ensured the filtering error systems to be asymptotically stable with the prescribed H∞ disturbance attenuation level.

In [17] the author explains point to point architecture of control system SCADA and DCS network and finally the mixed open loop/closed loop control developed a feedback controller for the Networked Control System to face the performance of packet delays, packet losses and limited bandwidth. The authors in [18] presented for all possible missing observations and all admissible parameter uncertainties, the robust H∞ controller with feasible linear matrix inequalities, which guarantees that the controlled output satisfies the H∞ performance constraints closed loop system is asymptotically mean square stable. The Predictive Observer Memoryless Output feedback controller and output feedback controller [19] was designed for Networked Control System for both network-induced delay and packet losses. The stability conditions are derived via both network-condition-dependent Lyapunov function and common quadric Lyapunov function. Based on the stability conditions corresponding controller design problems were analyzed for two discrete time models with lifting techniques into NCS. The networked induction motor model with network time delay was considered in [21] and the sufficient condition for asymptotical stability and state feedback control algorithm was obtained by employing Lyapunov function and LMI theory. Similarly [22] used Lyapunov function for stability analysis in a class of networked linear control system with stochastic input delay.

[24] – [28] the optimization technique called Particle Swarm Optimization (PSO) based PID controllers are studied for various applications. A novel PSO [24] based method was proposed for determining the optimal PID controller parameters, for speed control of a linear brushless DC motor. An Intelligent controller for DC motor drive is designed using PSO method [25] for formative the optimal PID controller tuning parameters. In [26] using PSO the optimal PID controller parameters of an Automatic Voltage Regulator (AVR) system was proposed. Using PSO algorithm to minimize a cost function subject to H∞ norm to design robust performance PID controller for fighter aircraft system was proposed in [27]. And in [28] a new PID tuning algorithm was proposed by the evolutionary programming, genetic algorithm and PSO technique to improve the performance of the PID controller in armature control DC motor.

Optimal integral state feedback control with genetic algorithm and kalman filter was proposed [29] for speed and position of DC motor. Performance degradation of networked control system by introducing random delays was addressed in [30] by deriving adaptive predictive functional control algorithm and by applying the concept of predictive functional control to a discrete state space model with variable delay. Bacterial foraging technique [31] was adapted to guide the search on the optimal parameters of PID controller in the parameters search space for automatic tuning of a PID controller for a UAV.

Xingwen Liu, and et. al. [32] analyzed the stability problem of continuous time positive systems with time varying delays. It is shown that such a system is asymptotically stable for any continuous delay if and only if the sum of all the system matrices is a Hurwitz matrix. The result is a time varying version of the widely known asymptotic stability criterion for control delay positive systems.

Wen & Li Yu [33] studied the stabilization problem for sampled data control systems with control inputs missing. The data missing rate and admissible data missing rate bound relations provide guidelines for the design of sampled data control systems with control inputs missing. Miroslav Krstic [24] established a time varying Lyapunov functional for the closed loop system for exponential stability. The Lyapunov functions using a back stepping transformation with time varying kernels and transforming the actuator state into a transport partial differential equation with a convection speed coefficient that varies with both space and time was constructed in order to study the stability under time varying input delay as compared to the results for constant input delays.

An estimation method [35] was proposed to compensate the packet dropout. Subsequently, a discrete time integral sliding surface involving dropout probability is introduced and sliding mode controller is designed for the existence of dropout of data packet in communication network in a feedback loop. In [36] the networked synchronization control problem for the coupled dynamic networks has been considered and a new closed loop dynamic error system with markovian jump parameters and interval time varying delays was constructed. Using Kronecker product and the stochastic Lyapunov stability theory, a delay depended stochastic stability criterion for the closed loop coupled dynamic error system has been derived in terms of linear matrix inequality which guarantees that the coupled dynamic network systems are stochastically synchronized.

In [39] the author presented a new model for NCS which involves communication constraints, varying transmission intervals and varying transmission delays based on Lyapunov, and explicit bound on the maximum allowable transmission interval and the maximum allowable delay which guarantee stability of NCS. The Nesic and Teel [41] presented an approach for stability analysis of NCS that decouples the scheduling protocol from properties of network free nominal closed-loop system. [42] extends [41] by stochastic deterministic protocols in the presence of random packet dropouts and inter transmission time. And they also proposed wireless scheduling protocol for non-linear NCS in [45]. The networked predictive control scheme for forward and feedback channels having random network delay was proposed in [43], and [44] addresses the problems of how uncertain delays are smaller than one sampling period which affects the stability of the NCS and also how these delays interact with maximum allowable transfer interval and the selected sampling period. Robust feedback controller design for NCS with uncertainty and the network induced delay has been addressed in [46] - [47], whereas [48] handled networked induction motor speed control by using linear matrix n equality (LMI) method. [40] measured the networked vehicle control performance using an H infinity norm with linear matrix inequalities conditions and markovian jumping parameters in communication losses. In case of time varying transmission model based NCSs has been proposed for stabilization problem.

The issues of limited bandwidth, time delay and data dropouts was taken into consideration when NCSs controllers were designed in [50] – [53]. A moving horizon method was applied as a quantized NCS in a practical context [50].

## Conclusion

Networks and their applications play a promising role for real-time high performance networked control in industrial applications. The major concern which affects the performance of the networked control systems are the network induced delays and data losses. This paper describes various techniques to compensate the challenges described by different authors. The networked control system performance depends on the control algorithm and the network conditions with their applications. Depending upon the control algorithm and network conditions the overall performance of the networked system may vary and hence the stability of the system.

## References

[1] Antsaklisz, P., and Baillieul, J., 2004, "Special Issue on Networked Control Systems," IEEE Transl. on Automatic Control, 49(9), pp. 1421-1423.
[2] Antsaklisz, P., and Baillieul, J., 2007, "Special Issue on Technology of Networked Control Systems," Proc. IEEE, 95(1), pp. 5-8.
[3] Branicky, M.S., Phillips,S.M., and Zhang, W., 2000, "Stability of NCS's: Explicit Analysis of Delay," Proc. American Control Conference, Chicaga, Illinios, 4, pp. 2352-2357.
[4] Almutairi, N.B., Chow, M.Y., and Tipsuwan, Y., 2001, "Network–Based Controlled DC motor with Fuzzy Compensation ," IECON '01 - 27th Annual IEEE industrial electronics society Conference, 3, pp. 1844-1849.
[5] Chow, M.Y., and Tipsuwan, Y., 2003, "Gain Adaptation of Networked DC Motor Controllers Based on QOS Variations," IEEE Transl. on Industrial Electronics, 50(5), pp 936 – 943.
[6] Lee, K.C., and Lee, S., 2002, "Implementation of Networked Control System using a Profibus –DP Network," International J. of the Korean Society of Precision Engg., 3(3), pp.12-20.
[7] Lee, K.C., Lee, S., and Lee, M.H., 2003, "Remote Fuzzy Logic Control of Networked Control System via Profibus DP," IEEE Transl. on Industrial Electronics, 50(4), pp 784 – 792.
[8] Tipsuwan, Y., and Chow, M.Y., 2003, "Control methodologies in networked control systems," Control Engg. Practice, 11(10), pp. 1099-1111.
[9] Tipsuwan, Y., and Chow, M.Y., 2003, "On the Gain Scheduling for Networked PI Controller over IP network," Proc. IEEE /ASME International Advanced Intelligent Mechatronics Conference, 1, pp. 640 -645.
[10] Atmutain, N.B., and Chow, M.Y., 2002, "PI Parameterization Using Adaptive Fuzzy Modulation (AFM) for Networked Control Systems – Part II: Full Adaptation," Proc. IEEE, 4, pp. 3158 – 3163.

[11] Atmutain, N.B., and Chow, M.Y., 2002, "PI Parameterization using Adaptive Fuzzy Modulation (AFM) for Networked Control Systems – Part I : Partical Adaptation," Proc. IEEE, 4, pp. 3152 – 3157.
[12] Cao, Y.C., and Zhang, W.D., 2006, "Modified Fuzzy PID Control for Networked Control Systems with Random Delays," Proc. World Academy of Science, Engg. and Tech., 12, pp. 313-316.
[13] Zhing, Y., Fang, H., and Wang, H.D., 2006, "Takagi-Sugeno Fuzzy Model Based Fault Detection for Networked Control Systems with Markov Delays," IEEE Transl. on Systems, Man and Cybernetics – Part B: Cybernetics, 36(4), pp. 924-929.
[14] Tian, X., Wang, X., and Cheng, Y., 2007, "A Self-Tuning Fuzzy Controller for Networked Control System," International J. of Computer Sciemce and Network Security, 7(1), pp. 97-102.
[15] Wang, Z., Yang, F., Ho, D.W.C., and Liu, X., 2007, "Robust H∞ Control for Networked System With Random Packet Losses," IEEE Transl. on Systems, Man, and Cybernetics- Part B: Cybernetics, 37(4), pp. 916 – 924.
[16] Gao, H., and Chen, T., 2007, "H∞ Estimation for Uncertain Systems With Limited Communication Capacity," IEEE Transl. on Automatic Control, 52(11), pp. 2070-2084.
[17] Gunasekaran, M., and Potluri, R., 2007, "Networked Control Systems and a mixed open loop/closed loop control," Proc. International Advances in Control and Optimization of dynamic System Conference, IISc, Bangalore, pp. 439 – 442.
[18] Yang, F., Wang, Z., Ho, D.W.C., and Gani, M., 2007, "Robust H∞ Control with Missing Measurements and Time Delays," IEEE Transl. on Automatic Control, 52(9), pp. 1666 – 1672.
[19] Li, H., Sun, Z., Liu, H., and Chen, M.Y., 2008, "Predictive observer-based control for networked control systems with network-induced delay and packet dropout," Asian J.of Control, 10(6), pp. 638-650.
[20] Zhang, H., Li, M., Yang, J., and Yang, D., 2009, "Fuzzy Model-Based Robust Networked Control for a Class of Nonlinear Systems," IEEE Transl. on Systems, Man and Cybernetics-Part A: Systems and Humans, 39(2), pp. 437-447.
[21] Ren, J., Li, C.W., and Zhao, D.Z., 2009, "Linearizing control of induction motor based on networked control systems," International J. of Automation and Computing, 6(2), pp. 192-197.
[22] Yue, D., Tian, E., Wang, Z., and Lam, J., 2009, "Stabilization of Systems with Probabilistic Interval Input delays and its applications to Networked Control Systems," IEEE Transl. on Systems, Man, & Cybernetics –Part B: Cybernetics, 39(4), pp. 939-945.
[23] Jia, X., Zhang, D., Hao, X., and Zheng, N., 2009, "Fuzzy H∞ Tracking Control for Nonlinear Networked Control Systems in T-S Fuzzy Model," IEEE Transl. on Systems, Man, & Cybernetics –Part B: Cybernetics, 39(4), pp. 1073-1079.

[24] Nasri, M., Pour, H.N., and Maghfoori, M., 2007, “A PSO optimum design of PID controller for a linear brushless DC motor,” World Academy of Sci. Engg. & Tech., 26, pp. 211-215.
[25] Allaoua, B., Gasbaoui, B., and Mebarki, B., 2009, “Setting up PID DC motor speed control alternation parameters using particle swarm optiminization stratery,” Leonardo Electronics J. of Prac. & Tech., 14, pp. 19-32.
[26] Gaing, Z.L., 2004, “A Particle Swarm Optiminization approach for optimum design of PID controller in AVR System,” IEEE Transl. on Energy Conversion, 19(2), pp. 384-391.
[27] Zamani, M., Sadati, N., and Ghartemani, M.K., 2009, “Design of an H∞ PID controller using particle swarm optimization,” International J. of Control, Automation and Systems, 7(2), pp. 273-280.
[28] Nagaraj, B., Subha, S., and Rampriya, B., 2008, “Tuning Algorithms for PID Controller Using Soft Computing Techniques,” International J. of Computer Sciemce and Network Security, 8(4), pp. 278-281.
[29] Delavari, H., Noiey, A.R., and Minagar, S., 2009, “Artificial Intelligent Controller for a DC Motor,” Advances in Computer Science and Engg., 6(2), pp. 842 – 846.
[30] Wang, X.L., Fei C.G., and Han, Z.Z., 2011, “Adaptive Predictive Functional Control for Networked control Systems with Random Delays,” International J. of Automation and Computing, 8(1), pp. 62-68.
[31] Oyekan, J., and Hu, H., 2010, “A novel bacterial foraging algorithm for automated tuning of PID controllers of UAVs,” Proc. IEEE International Information and Automation Conference, pp. 693-698.
[32] Liu, X., Yu, W., and Wang, L., 2010, “Stability Analysis for Continuous-time Positive Systems with time-Varying Delays,” IEEE Transl. On Automatic Control, 55(4), pp. 1024-1028.
[33] Zhang, W., and Yu, L., 2010, “Stabilization of Sampled-Data Control Systems with Control Input Misssing,” IEEE Transl. on Automatic Control, 55(2), pp. 447-452.
[34] Krstic, M., 2010, “Lyapunov Stability of Linear Predictor Feedback for Time-Varying Input Delay,” IEEE Transl. on Automatic Control, 55(2), pp. 554-559.
[35] Niu, Y., and Ho, D.W.C., 2010, “Design a Sliding Mode Control Subject to Packet Losses,” IEEE Transl. on Automatic Control, 55(11), pp. 2623-2628.
[36] Wang, Y., Zhang, H., Wang, X., and Yang, D., 2010, “Networked Synchronization Control of Coupled Dynamic Networks with Time-Varying Delay,” IEEE Transl. on Systems, Man, & Cybernetics –Part B: Cybernetics, 40(6), pp. 1468-1478.
[37] Gao, H., Zhao, Y., and Chen, T., 2009, “H∞ Fuzzy Control of Nonlinear Systems Under Unrealiable Communication Links” IEEE Transl. on fuzzy Systems, 17(2), pp. 265-278.
[38] Dong, H., Wang, Z., and Gao, H., 2009, “H∞ fuzzy Control for Systems with Repaeated Scalar Nonlinearities and Random Packet Losses,” IEEE Transl. on fuzzy Systems, 17(2), pp. 440-450.

[39] Heemels, W.P.M.H., Teel, A.R., Wouw, N.V.D., and Nesic, D., 2010, “Networked Control Systems with Communication Constraints: Tradeoffs Between Transmission Intervals, Delays and Performance,” IEEE Transl. Autom. Control, 55(8), pp. 1781-1796.
[40] Seiler, P., and Sengupta, R., 2005, “An H∞ Approach to Networked Control,” IEEE Transl. Autom. Control, 50(3), pp. 356-364.
[41] Nesic, D., and Teel, A.R., 2004, “Input-Output stability properties of networked control systems,” IEEE Transl. Autom. Control, 49(10), pp. 1650-1667.
[42] Tabbara, M., and Nesic, D., 2008, “Input-Output Stability of Networked Control Systems With Stochastic Protocols and Channels,” IEEE Transl. Autom. Control, 53(5), pp. 1160-1175.
[43] Lin, G.P., Xia, Y., Chen, J., Rees, D., and Hu, W., 2007, “Networked Predictive Control of Systems With Random Network Delays in Both Forward and Feedback Channels,” IEEE Transl. Ind. Electron., 54(3), pp. 1282-1297.
[44] Kim, D.S., Lee, Y.S., Kwon, W.H., and Park, H.S., 2003, “Maximum allowable delay bounds of networked control system,” Control Engg. Practice, 11(11), pp. 1301–1313.
[45] Tabbara, M., Nesic, C., and Teel, A.R., 2007, “Stability of wireless and wireline networked control systems,” IEEE Transl. Autom. Control, 52(9), pp. 1615-1630.
[46] Yue, D., Han, Q., and Chen, P., 2004, “State feedback controller design of networked control systems,” IEEE Transl. Circuits Systems II, 51(11), pp. 640-644.
[47] Yue, D., Han, Q., and Lam, J., 2005, “Network-based robust H∞ control of systems with uncertainty,” Automatica, 41(6), pp. 999-1007.
[48] Ren, J., Wen Li De, C., and Zhao, Z., 2009, “Linearizing Control of Induction Motor Based on Networked Control Systems,” International J. of Automation and Computing, 6(2), pp.192-197.
[49] Montestruque, L.A., and Antsaklis, P., 2004, “Stability of Model-Based Networked Control Systems with Time-Varying Transmission Times,” IEEE Transl. Autom. Control, 49(9), pp. 1562–1572.
[50] Goodwin, G.C., Haimovich, H., Quevedo, D.E, and Welsh, J.S., 2004, “A Moving Horizon approach to networked control system design,” IEEE Transl. Autom. Control, 49(9), pp. 1427–1445.
[51] Li, K., and Baillieul, J., 2004, “Robust quantization for digital finite communication bandwidth (DFCB) control,” IEEE Transl. Autom. Control, 49(9), pp. 1573–1584.
[52] Luo, R.C., and Chen, T.M., 2000, “Development of a multi-behaviour based mobile robot for remote supervisory control through the internet,” IEEE/ASME Transl. Mechatron., 5(4), pp. 376-385.
[53] Hespanha, J.P., and Naghshtabrizi, P., and Xu, Y., 2007, “A survey of recent results in networked control systems," Proc. IEEE, 95, pp. 138-162.
[54] Ogata, K., 1990, Modern Control Engineering, 4th ed., NJ: Prentice Hall, Englewood Cliffs.

[55] Ziegler, J.G., and Nichols, N.B., 1942, "Optimum settings for automatic controllers," Transl. ASME, 64, pp. 759-768.
[56] Lee, C.C., 1990, "Fuzzy logic in control systems: fuzzy logic controller-Part I," IEEE Transl.Syst.,Man,Cybern., 20(2), pp.404-418.
[57] Lee, C.C., 1990, "Fuzzy logic in control systems: fuzzy logic controller-Part II," IEEE Transl.Syst.,Man,Cybern., 20(2), pp. 419-435.
[58] Zheng, Y., Fang, H., and Wang, H.O., 2006, "Takagi-Sugeno Fuzzy-Model-Based Fault Detection for Networked Control Systems with Markov Delays," IEEE Transl. on Systems, Man and Cybernetics-Part B: Cybernetics, 36(4), pp. 924-929.