DESIGN AND EVALUATION OF NOVEL STRATEGY FOR NETWORKED CONTROL SYSTEM

M.Venkat Reddy[1], A.Yashwanth Reddy[2]
[1]Assistant Professor, Sree Dattha Institute of Engineering and Science, Sheriguda, Hyderabad,
[2]Assistant Professor, Sree Dattha Group of Institutions, Sheriguda, Hyderabad, India. Email:

Abstract
The Network Controlling Strategy (NCS) shall be deemed to be a controlling strategy where these controlling loops get closed by means of communicating networks. This pertaining features of these NCSs are by controlling and feedback signal is varied based on components of the system by means of data package via these networks. Network Controlling systems are kinds of distributed systems that employs united transmission mediums for sharing data between dissimilar components linked to these systems. In this paper, we are addressing these issues incorporated with design and development of Network controlling systems and also performance of these systems. This paper targets towards designing and implementations of Estimators for NCSs from communications and control points of view.
Keywords: Maximum Allowable delay bound (MADB), Quality of service (QOS) and Quality of performance (QOP).

1. INTRODUCTION

The most important feature of a NCS is that it connects cyberspace to physical space enabling the execution of several tasks from long distance. In addition, networked control systems eliminate unnecessary wiring reducing the complexity and the overall cost in designing and implementing the control systems. They can also be easily modified or upgraded by adding sensors, actuators and controllers to them with relatively low cost and no major changes in their structure. Moreover, featuring efficient sharing of data between their controllers, NCS are able to easily fuse global information to make intelligent decisions over large physical spaces. Their potential applications are numerous and cover a wide range of industries such as: space and terrestrial exploration, access in hazardous environments, factory automation, remote diagnostics and troubleshooting, experimental facilities, domestic robots, aircraft, automobiles, manufacturing plant monitoring, nursing homes and tele-operations. While the potential applications of NCS are numerous, the proven applications are few, and the real opportunity in the area of NCS is in developing real-world applications that realize the area's potential [1].

Advent and development of the Internet combined with the advantages provided by NCS attracted the interest of researchers around the globe. Along with the advantages, several challenges also emerged giving rise to many important research topics. New control strategies, kinematics of the actuators in the systems, reliability and security of communications, bandwidth allocation, development of data communication protocols, corresponding fault detection and fault tolerant control strategies, real-time information collection and efficient processing of sensors data are some of the relative topics studied in depth. The insertion of the communication network in the feedback control loop makes the analysis and design of an NCS complex, since it imposes additional time delays in control loops or possibility of packages loss. Depending on the application, time-delays could impose severe degradation on the system performance.

To alleviate the time-delay effect, Y. Tipsuwan and M-Y. Chow, in ADAC Lab at North Carolina State University, proposed the Gain Scheduler Middleware (GSM) methodology and applied it in iSpace. S. Munir and W.J. Book (Georgia Institute of Technology) used a Smith predictor, a Kalman filter and an energy regulator to perform teleoperation through the Internet. K.C. Lee, S. Lee and H.H. Lee used a genetic algorithm to design a controller used in a NCS. Many other researchers provided solutions using concepts from several control areas such as robust control, optimal stochastic control, model predictive control, fuzzy logic etc.

Moreover, a most critical and important issue surrounding the design of distributed NCSs with the successively increasing complexity is to meet the requirements on system reliability and dependability, while guaranteeing a high system performance over a wide operating range. This makes network based fault detection and diagnosis techniques, which are essential to monitor the system performance, receive more and more attention. In feedback control systems, it is important that sampled data should be transmitted within a sampling period and stability of the system should be guaranteed in spite of the performance degradation [7]. This certain bound is called a Maximum Allowable Delay Bound (MADB).

The functionality of a typical NCS is established by the use of four basic elements:

- Sensors to acquire information
- Controllers to provide decision and commands
- Actuators to perform the control commands
- Communication network to enable exchange of information.

2. NETWORKED CONTROL SYSTEM

In the past, traditional control systems had a single centralized control unit, which controlled all other processes and devices (sensors and/or actuators).

It had various disadvantages like single point of failure, poor reliability, Poor performance and inability to support advanced distributed control scheme.

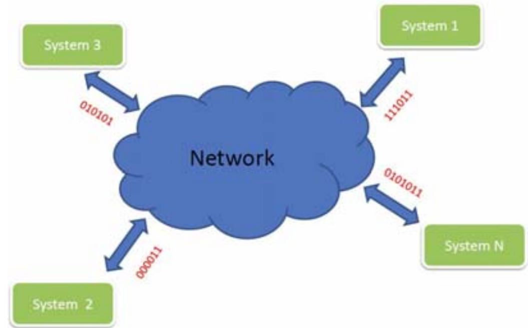

Fig.1 Articulation of an NCS

The solution currently adopted to address modern control problems is to distribute the processing functions of these systems over several physical nodes, each dedicated to a part of the control process and to a group of sensors/actuators. These nodes cooperate with each other, communicating through a shared physical channel which forms a Networked Control System.

These common-bus systems require less complex wiring reducing the setup and maintenance costs. At the same time, they also reduce the possibility of a single fault affecting the whole system. Fig.1 shows the Schematic diagram for an NCS.

Networked Induced Delays are dependent on the configuration of the network and the given system [2,3] Fig 2. shows the schematic of a feedback control system with network-induced delays. Major advancements over the last decades in wired and wireless communication networks gave rise to the new paradigm of Networked Control Systems (NCS). Within this paradigm, sensing and actuation signals are exchanged among various parts of a single system or among many subsystems via communication networks; the latter scenario is seen in Fig. 1.

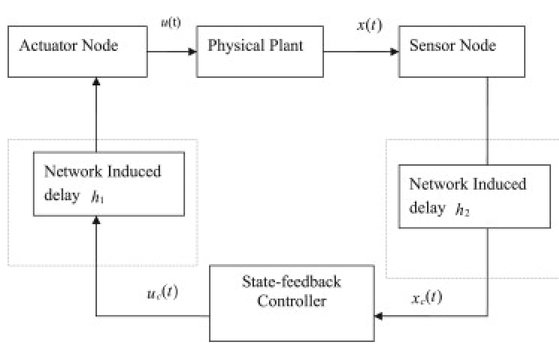

Fig.2 Schematic of a feedback control system with network-induced delays

3. TYPICAL MIMO SYSTEM

Consider a discrete time LTI MIMO system m inputs and r outputs as shown in Fig 3 and described as follows.

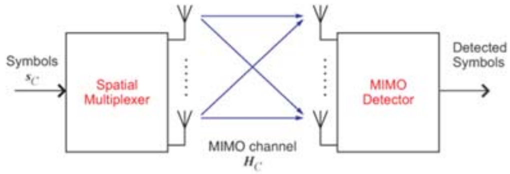

Fig.3 A standard MIMO system

$$
\begin{aligned}
&X(k+1) = AX(k) + BU(k) + BD(k) \\
&Y(k) = CX(k) \\
&with \\
&U(z) = K(z)E(z) \\
&= K(z)[R(z) - (CX(z) + N(z))]
\end{aligned} \tag{1}
$$

Where R,D,N and K are the reference ,disturbance, sensor noise and closed loop controller respectively. The states of the system can be expressed as follows:

$$
\begin{aligned}
&X(z) = [zI - \psi(z)]^{-1}[BK(z)R(z) - BK(z)N(z) + BD(z)] \\
&where \\
&\psi(z) = (A - BK(z)C)
\end{aligned} \tag{2}
$$

If the number of inputs and outputs is large, and the System is physically distributed over a wide area, it may make sense to implement the MIMO system in a distributed fashion over a network. The i th node contains the sensor for the i th output and the actuator for the ith input of the system. Fig.4 gives the distributed implementation of MIMO system. For the distributed configuration to achieve the same performance as the centralized case each error (or Yi) must be communicated over the network to the other nodes at every sample time.

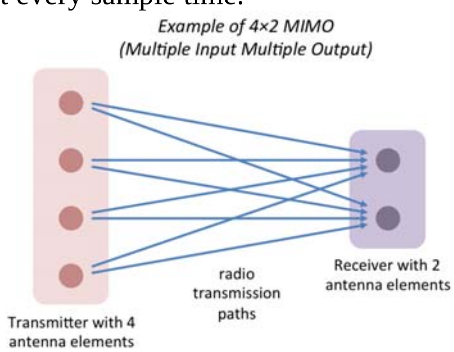

Fig. 4 Distributed implementation of MIMO system [4-10]

4. STATE ESTIMATOR FRAMEWORK

Basically, the proposed state estimator includes communication logic which compares the actual output of the ith node with the estimated output of the ith node and manages the communication from the ith node to the entire system. For example, if the difference between the actual and estimated output of the ith node is greater than a threshold value, either the actual output or the estimated states of the ith node are broadcast to the entire system. At that time, the estimator states representing the ith node are updated to reflect their current values in all estimators. This threshold communication logic is used.

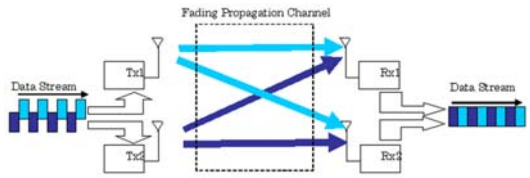

Fig.5 Proposed state estimator scheme

Consider the system described above. When this system Fig.5 is implemented with the proposed estimator the equations become as

$$
\begin{aligned}
&X^*(k+1) = AX^*(k) + BU^*(k) + BD(k) \\
&Y^*(k) = CX^*(k) \\
&with U^* = KE^* + E\Gamma - K_{dia}\Gamma \\
&= KE^* + K_{off}\Gamma
\end{aligned} \tag{3}
$$

The states of the system is expressed as

$$
\begin{aligned}
&X^*(z) = [zI - \psi(z)]^{-1}[BK(z)R(z) + BK_{off}(z)\Gamma(z) \\
&-BK(z)N(z) + BD(z)]
\end{aligned} \tag{4}
$$

The controller output U* differs from U since U* is computed using both actual and estimated errors. The difference between actual and estimated outputs can be described as

$$
\begin{aligned}
\tau &= Y^* - \hat{Y} \\
&= \hat{E} - E^*
\end{aligned} \tag{5}
$$

Thus the actual and estimated state differ only by additional term

$$BK_{off}(z)T(z) \tag{6}$$

This communication logic is bound by the threshold value H, which is defined by the control system designer. Hence the standard and distributed implementation of a Multiple Input Multiple Output system and its estimator framework is worked out.

5. USE OF STATE ESTIMATORS

An example of a networked two-agent system with state estimator and communication module is shown in Fig.6 and the schematic diagram of the Control/Communication module is depicted in Fig.7The basic idea is to let one agent use estimated states for control actions and broadcast its current states to other agents if estimation is not acceptable. Next to the agent is one estimator which computes the states of the agent and the other agents, based on any well-designed estimation algorithm [10]. The main functionality of the Control/ Comm. module is to compute the difference of the true and estimated states of the agent, control the communication frequency, and update the estimated states by true states. MIMO (Multiple Input Multiple Output) is expected to become popular as a solution to enhance data throughput and quality of communication in complex propagation environments. The technology has attracted a great deal of attention recently because of the critical role it plays in the IEEE 802.11n standard that is nearing completion with "pre-n" system-level products already on the market. But there are several different interpretations and implementations considered to be MIMO technology and MIMO will be adopted in many of the wireless and mobile communication systems in the future. This article discusses the IEEE 802.11n system currently being proposed and explores the expected design and measurement challenges for a specific type of MIMO system implementation.

The IEEE 802.11n system promises to have enhanced data rates, better spectral efficiency, better quality and more robust system when compared to the existing IEEE 802.11a/b/g system. Several ideas have been considered to support these requirements. Data rates have been enhanced by increasing the number of sub-carriers from the 54 sub-carriers used in 802.11a/g systems to 114 sub-carriers. However, this requires slightly over twice the current occupied spectrum and does not contribute to the robustness or spectrum efficiency. Therefore, it was decided to adopt the MIMO technology in IEEE 802.11n standards. MIMO is a family of techniques for multi antenna wireless transmission and reception that increases the achievable data throughput within the same occupied bandwidth, increases quality of communication, and allows dramatically increased spectral efficiency. While offering substantial benefits to system performance, it also increases the challenges in design and system evaluation and validation. New measurements need to be considered for testing MIMO systems

There are many was to accomplish MIMO processing, including MIMO Multiplexing, MIMO Diversity and others. IEEE 802.11n will adopt Spatial Division Multiplexing (SDM) which is a form of MIMO Multiplexing. The diversity gain and throughput are improved through the use of multiple antennas and specialized coding schemes. In principal, increasing the number of antenna branches enables data throughput to increase geometrically with the increasing number of antenna pairs. IEEE 802.11n will support up to 4 transmitting antennas. While there are multiple MIMO configurations, this article will examine the use of a 2X2 MIMO system (2 transmitting antennas and 2 receiving antennas). Different data packets are transmitted (Tx1 and Tx2) on each antenna, and signals are combined in free space environment.

Spatial diversity and the multipath propagation are important elements of the MIMO implementations, and the important challenges in the design of the system. At the receiver end of the system, a combination of the multiple transmission paths are received at each of the receive antenna (Rx1 and Rx2).

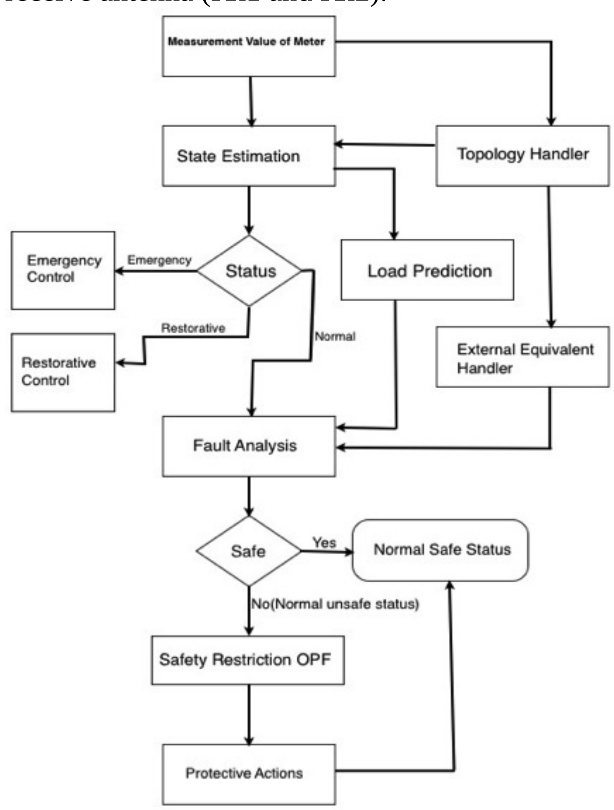

Fig.6 Networked two-agent system with state estimator and communication module

The channel characteristics between the antenna branches will be different. The physical separation distance (spatial diversity) and the spatial fading correlation coefficient between antenna branches have influence on the data throughput. Designs will be required to take special care of each antenna position to get minimum spatial fading correlation. In the receiver (Rx1 and Rx2), the Tx1 and Tx2 signals must be split from each of the received signals so the transmitted data can be restored to the original Tx1 and Tx2 signals. The probability of increasing the quality of transmission improves by increasing the number of receiving antennas. In order to improve the efficiency of transmission for a MIMO system, a key performance parameter will be how accurately the receiver can split the transmitted signals by using the different propagation of characteristics of each channel.

The designer must not only consider the characteristics of transmitter and receiver; but it also necessary to design systems architecture tolerant of the channel propagation characteristics. In a typical environment (office or home), the channel propagation characteristics will vary dramatically from moment to moment as 'mobile interferers' such as people move about the room. In consideration of such a dynamically changing propagation environment, calculation of the channel propagation characteristics of every packet is required to optimizing transmission. Therefore, advanced algorithms for optimization must be accurate, adaptive, and computationally fast. Here, the estimator1and 2 computes $x1e$ and $x2e$ .At normal scenario, i.e. no communication required,Agent1 operates based on its own state $x1$ and estimated state of Agent2, $x2e$.

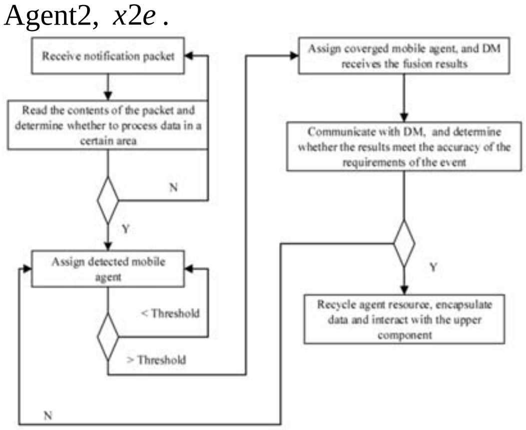

Fig.7 Flowchart of communication module

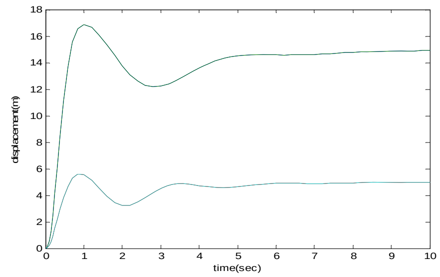

Fig.8 A mass-spring damper system.

When Control/Comm. module 1 receives new $x2$, it informs Agent 1to use newly arrived $x2$ instead of estimated state $x2e$. In addition, Control/Comm module 1 broadcasts $x1$ to Agent 2 if $|x1-x1e|$ is larger than a predefined threshold, $h1$. Similar estimation and communication mechanisms are designed at Agent 2 and other agents.Fig.7 gives the Schematic diagram of the communication module. The system can be defined by the following differential equations.

$$\begin{bmatrix} \dot{x}_1 \\ \ddot{x}_1 \\ \dot{x}_2 \\ \ddot{x}_2 \end{bmatrix} = A \begin{bmatrix} x_1 \\ \dot{x}_1 \\ x_2 \\ \dot{x}_2 \end{bmatrix} + B \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

with

$$A=\begin{bmatrix} 0 & 1.0000 & 0 & 0 \\ -1.0000 & -0.2000 & 1.0000 & 0.2000 \\ 0 & 0 & 0 & 1.0000 \\ 0.5000 & 0.1000 & -2.5000 & -0.1500 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 \\ 0.9091 & 0 \\ 0 & 0 \\ 0 & 0.45451 \end{bmatrix} \qquad C=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$A0=\begin{bmatrix} 0 & 1.0000 & 0 & 0 \\ -1.0000 & -0.2000 & 1.0000 & 0.2000 \\ 0 & 0 & 0 & 1.0000 \\ 0.5000 & 0.1000 & -2.5000 & -0.1500 \end{bmatrix}$$

$$B0=\begin{bmatrix} 0 & 0 \\ 1.0000 & 0 \\ 0 & 0 \\ 0 & 0.5000 \end{bmatrix} \qquad C0=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Where,

A,B,C and A0,B0,C0 are actual and nominal parameter values. A suitable controller (K) can be designed using any standard controller design technique.**U**sing MATLAB/Simulink the plant is simulated without and with controller and the simulation results are shown.

6. CONCLUSION

Using the states of the estimator designed above, a communication module is designed. This communication module compares the estimated values with the actual output. If the error difference exceeds a pre-defined threshold given by the design engineer, it transmits the estimated value to all other nodes. Else, no communication occurs between other nodes. Thus by reducing the communication between nodes based on the estimated values, the desirable control and communication performance can be obtained.

REFERENCES

[1] T. C. Yang, "Networked Control System: a brief survey", Proceedings of IEEE Conference on Control Theory Applications, Vol.153, No.4, July 2006, pp 403 – 412.

[2] Magdi S. Mahmoud, Abdulla Ismail, "Role of Delays in Networked Control Systems", Proceedings of IEEE Conference on Control System, 2003, pp 40 – 43.

[3] Shanbin Li, Zhi Wang, Youxian Sun, "Fundamental Problems of Networked Control System from the view of Control and Scheduling", Proceedings of IEEE Conference on Control Theory Applications, 2002, pp 2503 – 2508.

[4] Yu jianyong, Yu Shimin, Wang Haiqing, "Survey on the Performance Analysis of Networked Control Systems", IEEE International Conference on Systems, Man and Cybernetics, 2004.

[5] K.J. Astrom and B. Wittenmark, Computer Controlled Systems. Third Edition, Prentice - Hall, 1997.

[6] Dan Henriksson, Anton Cervin, Karl-Erik Arzen "TRUETIME: Real – time Control System Simulation with MATLAB/Simulink", Department of Automatic Control, Lund Institute of Technology, Sweden.

[7] W. Zhang, M.S. Branicky, and S.M. Phillips, "Stability of networked control systems", IEEE Control systems magazine, Vol. 21(1), pages: 84 – 99, Feb. 2001.

[8] Feng-Li Lian, John K. Yook, Dawn M. Tilbury, James Moyne," Network Architecture and Communication Modules for Guaranteeing Acceptable Control and Communication Performance for Networked Multi-Agent Systems", IEEE Transactions on Industrial Informatics, vol. 2, No. 1,February 2006.

[9] Feng-Li Lian,James Moyne and Dawn Tilbury," Network Design Consideration of Distributed Control Systems", IEEE Transactions on Control Systems Technology, Vol.10, No. 2 , March 2002.

[10] John K. Yook, Dawn M. Tilbury, Member, IEEE, and Nandit R. Soparkar," Trading Computation for Bandwidth: Reducing Communication in Distributed Control Systems Using State Estimators" IEEE Transactions on Control systems technology, vol.10,no. 4, July 2002 .