


# Networks and Control

## By Linda G. Bushnell, Guest Editor

The title of this special section updates a common juxtaposition in control circles. The scale of applications of interest is no longer captured simply by "systems and control"; it is increasingly the *networked* nature of systems that is drawing attention.

This special section presents five articles that can be classified into two distinct areas of "networks and control." The first area considers the control of communication networks, which falls into the broader field of information technology. We include two articles in this area, focusing respectively on new research topics in wireless networks and congestion control for asynchronous transfer mode (ATM) networks. The last three articles are in the area of networked control systems, where one or more control loops are closed via a serial communication channel. These articles cover stability issues, application issues, and several standard bus protocols. All five articles discuss various new research areas for control engineers. Applications of this research include control and communications of active, intelligent, dynamic networks; distributed sensor systems; secure, reliable wireless communication; and control of multivehicle formations.

Clearly, the area of communication networks is wide open to control researchers seeking interesting problems. This is a "hot" area, and we should not miss the opportunity to expand our horizons and further our impact. Industry as well as academia is hiring communication network engineers as never before.

The first article in this special section is authored by Kumar and is titled "New Technological Vistas for Systems and Control: The Example of Wireless Networks." The article discusses new opportunities for systems and control researchers in wireless networks-with the cost of wireless connectivity becoming competitive with wireline, such opportunities are rapidly arising. The specific wireless networks discussed are known as packet radio networks, or multihop mobile radio networks, or just *ad hoc* networks. An example is a "smart house," where the appliances, lights, and HVAC system communicate and coordinate schedules. The basic idea of such a network is to transfer packets from their sources to their destinations reliably and efficiently. This includes choice of broadcast power levels and timing of transmissions. This article considers several important issues in wireless network design and implementation, including quality of service and the power control, medium access control, routing, and transport capacity problems. Several protocols and algorithms are suggested for solving these problems and for illustrating the ideas presented in the article.

The article on available bit rate congestion control in ATM networks, by Imer, Compans, Başar, and Srikant, starts with a brief introduction to ATM networks, the available bit rate (ABR) service, and mechanisms for controlling source rates, which can be through binary or explicit feedback. ATM is the underlying technology that will make broadband integrated

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services digital network (B-ISDN) possible, which is necessary for high definition television (HDTV) and real-time video. The ABR rate control problem is formulated as an optimal control problem in which the deviation of the queue length from a target and the deviation of the source rates from their allocations are both minimized. Simplifying assumptions include: 1) the network has a single bottleneck link, 2) the saturation nonlinearity of queue processes is ignored, and 3) the service rate is an autoregressive process driven by white Gaussian noise. The issue of delays in receiving information and taking action is also discussed.

The following three articles focus on the area of networked control systems, which is of current theoretical as well as practical interest. The area of networked control systems (NCSs, for short) is new to the academic control community-journal articles in this area, for example, are still rare-but it is not new to industry. NCSs are used in manufacturing plants, aircraft, automobiles and HVAC systems, to name a few key target applications. The idea is to use serial communication networks to exchange system information and control signals between various physical components of the systems that may be physically distributed. Standard serial communication technologies have been adapted to this context, such as Ethernet, IEEE 802.11 wireless, multidrop RS-485, and daisy-chained RS-232. Specialized network protocols have been developed, including controller area network (CAN) for automotive and industrial applications, BACNet for building automation, and Fieldbus for process control (see panel for Web resources). All of these protocols are used extensively in industry to reduce maintenance, lower cost, reduce weight and power, simplify installation, and improve reliability.

The first article, by Walsh and Ye, on scheduling for NCSs, explains the place of networked control systems in the overall spectrum of control/communication systems. The authors raise important issues associated with controlling systems over networks and present relations between closed-loop stability and the size of transmission deadlines for certain types of scheduling. A novel scheduling policy, the maximum error first (mef) - try once discard (TOD) policy, is introduced and compared with static scheduling. The notion of "maximum allowable transfer interval" is defined. Sufficient conditions are derived for exponential stability of networked control systems. The article also provides evidence of superiority of the dynamic TOD scheduler over static scheduling via simulations and results from two experiments. The information will be useful for control engineers who want to choose the best scheduling policy for their specific networked control application.

In the article "Performance Evaluation of Control Networks: Ethernet, ControlNet, and DeviceNet," by Lian, Moyne, and Tilbury, various types of control networks are explored as communication backbones for a networked control system connecting sensors, actuators, and controllers. A control network, unlike a data network, has the capability to support real-time or time-critical applications. A data network supports large data packets, infrequent bursty transmissions, and high data rates. Control networks, on the other hand, support small, frequent packets among a large set of nodes to meet time-critical requirements. The protocols discussed in the article include Ethernet bus (CSMA/CD), token-passing bus (e.g., ControlNet), and CAN bus (e.g., DeviceNet). Details are given for the medium access control sublayer protocol for each control network. For each protocol, key network parameters are discussed, such as network utilization, magnitude of expected time delay, and characteristics of time delay. Results are presented via simulations.

**For more information on communication network technologies, see the following Web sites:**

**Ethernet:**
**http://www.webopedia.internet.com/TERM/E/Ethernet.html**

**Fieldbus:**
**http://www.fieldbus.org**

**CAN:**
**http://www.kvaser.se/can/index.htm**

**BACNet:**
**http://www.bacnet.org/**

**ControlNet:**
**http://www.controlnet.org/**

Conventional control theories such as synchronized control and nondelayed sensing and actuation must be reevaluated prior to application to networked control systems. The article titled "Stability of Networked Control Systems," by Zhang, Branicky, and Phillips, uses techniques from digital control systems, hybrid systems, and asynchronous systems to discuss important issues for networked control systems over local area networks. These issues include network-induced delays among the controller, sensors, and actuators; multiple-packet transmissions of plant outputs; and the case of lost packets (called *packet dropouts*). The plant studied via simulation is a MIMO LTI model with a discrete-time state feedback controller. The authors discuss fundamental issues for systems where network delay is introduced into the feedback. Stability results are derived for constant delays in the system. Estimators are used to compensate for sensor delays under time synchronization of the controllers and sensors. Asynchronous dynamical system (ADS) techniques are used to analyze the average stability of systems with lost packets.

In summary, the applications of our skills as control engineers to increasingly distributed, interconnected systems are pervasive. Whether it's the control *of* a network or control *through* a network, exciting prospects for innovation and impact exist.