International Workshop on Networked Control Systems, Shenzhen, Dec. 20-21, 2009
Program for Day 1

8:50 **Workshop Opening Remarks**

Session 1: Chaired by Lihua Xie

9:00 – 9:30 John Baillieul
Communication by Means of Controlled Dynamical Systems

9:30-10:00 Richard Murray
Information Dynamics for Networked Feedback Systems

10:00-10:30 David Hill
Synchronization of Dynamical Networks with Non-identical Nodes: Criteria and Control

10:30-10:50 Coffee Beark

Session 2: Chaired by Minyue Fu

10:50-11:20 Dagan Nesic
Observer Design for Networked Control Systems: an Emulation Approach

11:20-11:50 Ishii Hideaki
Distributed Randomized PageRank Computation Based on Web Aggregation

11:50-12:20 Shinji Hara
Decentralized Cooperative Control for Multi-Agent Dynamical Systems: A Unified Approach Based on Systems with Generalized Frequency Variables and Its Applications

Lunch

Session 3: Chaired by Huanshui Zhang

1:30-2:00 Joao Hespanha
Protocols for Networked Control Systems

2:00-2:30 Jie Chen
Performance of Networked Feedback Systems: Tracking and Power Allocation

2:30-3:00 Li Qiu
Multivariable Networked Stabilization with Channel Resource Allocation

3:00-3:20 Coffee Break

Session 4: Chaired by Weizhou Su

3:20-3:50 Karl Johansson
Event-based control for wireless systems

3:50-4:20 Lihua Xie
Minimum Data Rate and Channel Capacity for Stabilization of Linear Systems over Lossy Networks

4:20-4:50 Minyue Fu
Some Recent Results on Quantized Feedback Control

International Workshop on Networked Control Systems, Shenzhen, Dec. 20-21, 2009
Program for Day 2

8:45 **Workshop Opening Remarks**

Session 1: Chaired by Hailong Pei

9:00 – 9:30 Tianyou Chai
Issues on Optimal Control of Complex Industrial Processes and Networked Control

9:30-10:00 Han-Fu Chen
Stochastic Methods for Seeking Consensus of Networked Agents

10:00-10:20 Coffee Beark

Session 2: Chaired by Jie Chen

10:20-10:50 Guanrong Chen
Pinning Control of Complex Network Synchronization

10:50-11:20 Haitao Fang
Convergence Properties of Some Networked Systems with Noisy Observations

11:20-11:50 Xinping Guan
Wireless Networking Theory and Application

11:50-12:20 Zhihong Guan
Tracking Performance Limitations: From Classical Control Systems to Networked Control Systems

Lunch

Session 3: Chaired by Li Qiu

2:00-2:30 Wang Xiaofan
Flocking Control with a Fraction of Informed Agents

2:30-3:00 Weizhou Su
Optimal Tracking and Tracking Performance Constraints from Quantization

3:00-3:30 Zhang Huanshui
New Estimator and Duality of Control for Multiplicative Noise Systems with Applications to Packet Dropping and Multiple Input Delay Systems

Talk **Title/Abstracts** (next page)

Lihua Xie

Title: Minimum Data Rate and Channel Capacity for Stabilization of Linear Systems over Lossy Networks

Abstract: One of the main challenges in networked control systems is the analysis and synthesis of control over limited rate feedback channels. The problem of minimum data rate for stabilization of linear systems has attracted significant interest in the past decade and it is now well known that under perfect communications the minimum data rate is related to the unstable engenvalues of the open-loop system. Another important issue in networked control is the uncertainties induced by the network such as packet losses. In this talk, we shall discuss the minimum data rate for mean square stabilization over lossy networks. The packet losses process is modeled as an i.i.d. or Markov process. We show that the minimum data rate can be explicitly given in terms of the unstable eigenvalues of the open-loop system and the packet loss rate for the i.i.d. case or the transition probabilities of the Markov chain for the Markovian packet losses case. The number of additional bits required to counter the effect of the packet losses on stabilizability is completely quantified. We shall also discuss the problem of minimum channel capacity for mean square stabilization of linear systems.

Minyue Fu

Title: Some recent results on quantized feedback control

Abstract: Quantized feedback control deals with the problem of joint design of feedback controller and quantizer. The aim is to ensure closed-loop stability and good performance under a given bit rate constraint. This is one of the key problems in networked control systems. In this talk, we will discuss some of the recent results on this research problem for linear systems. Firstly, we will discuss the so-called minimum data-rate for feedback stabilization and show that this rate is attainable via a variable-rate logarithmic quantizer. This result offers some new understanding about logarithmic quantization. Secondly, we will consider the so-called quantized LQG control problem which is generalized from the classical LQG problem but with a fixed bit-rate constraint for feedback. The focus here will be on the potential generalization of the classical separation principle. A counter-example will be given to show that full separation of the quantizer, state estimator and state feedback controller is not possible in general. This will be followed by a result which says that, by incorporating a linear predictive coding scheme for state estimation, approximate separation indeed holds when the bit rate is relatively high. This result will be complemented by a stability analysis which shows that, with a careful choice of the quantization levels, the quantized LQG system designed using this separation scheme enjoys closed-loop stability.

John Baillieul

Communication by Means of Controlled Dynamical Systems

Abstract: In both the natural world and in competitive team sports, individuals communicate with each other by means of actions. These types of communications are typically dependent on context in that a particular motion or gesture will indicate something related to the current activity. Motions will frequently be executed so as to be maximally apparent to fellow team (or herd) members while at the same time revealing little or nothing to adversaries. This talk will describe current research on communication-through-action in which controlled dynamical systems play the role of a communications medium. In the context of linear time invariant input-output systems,
we shall describe the design of inputs that steer the state of a system in prescribed ways while at the same time encoding information that may be decoded from observed output. The talk will also mention results on the design of motion-based communication for autonomous robot vehicles in which information is transmitted from one vehicle to another by means of controlled relative motion patterns. Finally, we shall discuss the standard parts problem and connections with with
quantum communication.

Richard Murray

Title: Information Dynamics for Networked Feedback Systems

Abstract: Increases in fast and inexpensive computing and communications have enabled a new generation of information-rich control systems that rely on packet-based communication protocols, multi-threaded execution and distributed optimization in increasingly sophisticated ways. An important element of analyzing and designing these systems is to carefully track the dynamics of information in the system, including the role of the topology of the information flow in the overall dynamics of the system. This talk will describe recent results in exploring the effects of topology on the dynamics of networked control systems, including stability, performance and robustness guarantees. Applications include multi-vehicle systems performing cooperative tasks and autonomous systems with high-performance, distributed processing.

Li Qiu

Title: Multivariable Networked Stabilization with Channel Resource Allocation

Abstract: In this talk, we will survey the history of an instability measure of an LTI system and its connections with various feedback control problem. Then we will present its connections to networked control problems of multivariable systems. In such problems, communication resource allocation among various signal transmission channels becomes a design issue in addition to the usual controller design. We will see that some optimal and robust control problems arising in networked control are nontraditional and highly nonconvex but can be nicely and analytically solved, and the solutions are given in terms of the instability measure.

Dagan Nesic

Title: Observer design for networked control systems: an emulation approach

Abstract: Emerging control applications, such as drive-by-wire cars, often require some control loops to be closed over a network. Motivation for using this set-up comes from lower cost, ease of maintenance, great flexibility, as well as low weight and volume. This motivates research into networked control systems (NCS) in which one or several control loops are closed via a network. Recently we proposed an approach for stabilization of NCS where controller design is done via an approach that is similar to emulation in sampled-data systems. In the first step of this approach one designs a controller ignoring the network and in the second step the controller is implemented over the network with an appropriate protocol and, finally, with sufficient! ly fast sampling one can show robust stability of NCS. We also characterized the class of protocols that are amenable for this emulation approach and we refer to them as globally exponentially (asymptotically) stable protocols. The purpose of this talk is to present our recent results on the emulation approach for observer design for NCS.

Karl Johansson

Event-based control for wireless systems

There is a growing deployment of wireless networks in industrial control systems. The lower installation cost and easier system reconfiguration for wireless devices can have a major influence on future distributed control systems. There is however a lack of theory for the design of these networked control systems. Traditional sampled-data control theory is often not suitable for wireless control systems, because of cross-layer couplings and resource constraints not present in wired systems. In this talk, we will present a new design paradigm for networked control that handles uncertainty and limited resources using cross-layer information. Event-triggered sensing and control provides a more scalable and efficient trade-off between control performance and communication cost. By making transmissions only when needed and taking decisions locally at the sensor and actuator nodes, it is possible to minimize the use of communication resource. A novel design framework that allows the system developer to utilize the freedom provided by recently proposed event- and time-triggered communication protocols will be outlined. The talk will be supported by ongoing case studies with Swedish industry. The presentation is based on joint work with collaborators at KTH.

Joao Hespanha

Title: Protocols for Networked Control Systems

Network Control Systems (NCSs) are spatially distributed systems in which the communication between sensors, actuators and controllers occurs through a shared band-limited digital communication network. The use of a multi-purpose shared network to connect spatially distributed elements results in flexible

architectures and generally reduces installation and maintenance costs. Consequently, NCSs have been finding application in a broad range of areas such as the automotive and aerospace industries, mobile sensor networks, remote surgery, automated highway systems, and unmanned aerial vehicles.

The interest in NCSs has been steadily rising due to several factors:

* Low-cost, low-power, small embedded processors are widely available, which permits endowing sensors and actuators with local processing and sophisticated network protocols.
* Low-power, high-bandwidth digital communication is widely available to interconnect a large number of sensors, actuators, and controller nodes.

Inexpensive computation and ubiquitous embedded sensing, actuation, and communication provide tremendous opportunities for societal impact, but also great challenges in the design of networked control systems, because the traditional unity feedback loop that operates in continuous time or at a fixed sampling rate is not adequate when sensor data arrives from multiple sources, asynchronously, delayed, and possibly corrupted.

In this talk we review some of the challenges involved in closing feedback loops over communication networks. Our focus will be on issues related to variable sampling, delays, drops, and medium access control/scheduling. A key point that we would like to make is that networked control applications can profit significantly from the development of communication protocols specific for these systems.

Ishii Hideaki

Title: Distributed Randomized PageRank Computation Based on Web Aggregation

Abstract: The so-called PageRank algorithm has been used at Google in order to find proper ranking of search results. It quantifies the importance of each page based on the link structure of the web in such a way that links from important pages increases the significance of that page. In our recent work, we have proposed a distributed randomized approach for the PageRank computation. The algorithm is distributed in the sense that the pages find their own values by communicating with linked pages. The protocol can be implemented in an asynchronous manner since communication takes place at random instants. We present several extensions building upon this approach to improve the computation and communication load for the algorithm. In particular, a scheme is developed to systematically aggregate the web pages while maintaining the performan Title:

Decentralized Cooperative Control for Multi-Agent Dynamical Systems:
A Unified Approach Based on Systems with Generalized Frequency Variables and Its Applications

Abstract

This talk is concerned with decentralized cooperative control for multi-agent dynamical systems. We first show several fundamental results on stability and performance analysis based on a theoretical framework so called a class of linear time-invariant systems with generalized frequency variables. The

results include a Hurwitz type stability criterion, which can be reduced to a linear matrix inequality (LMI) feasibility problem involving generalized Lyapunov inequalities, methods of H_2-norm computation, and H_infty-norm conditions. We then introduce a cooperative stabilization problem by constant output feedback and examine the properties with examples of inverted pendulum systems. The last part is devoted to an application of oscillatory behaviors in a class of gene regulatory networks.
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Shinji Hara

Title: Decentralized Cooperative Control for Multi-Agent Dynamical Systems: A Unified Approach Based on Systems with Generalized Frequency Variables and Its Applications

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David Hill

Title: Synchronization of Dynamical Networks with Non-identical Nodes: Criteria and Control

Abstract: Dynamical network models have emerged recently in systems theory to describe many types of interconnected systems occurring in practical systems. The behaviour and control of such systems is being studied in terms of node dynamics, connectivity in the system graph and coupling parameters. A key collective behaviour is synchronization. Most results coming from network science and some related ones in multi-agent systems assume all the nodes are identical. However, for many practical systems, such as power systems, synchronization is essential and the nodes are not identical. This talk will present relaxed sync properties, stability criteria and some insights into control of such dynamical networks.

Jie Chen

Title: Performance of Networked Feedback Systems: Tracking and Power Allocation

Abstract: In this talk I shall present our recent work on tracking problems in a networked feedback setting. While there has been notable advance in the study of stabilization of networked control systems and fundamental limits have been discovered on network characteristics such as channel capacity,

quantization precision, etc, required to achieve stabilization, performance problems beyond stabilization prove more challenging and remain largely an untapped area. This work sets out to investigate the tracking performance of networked control systems, wherein we employ an additive white Gaussian noise model for the feedback channel. We attempt to derive explicit expressions for the minimal tracking error attainable under the channel constraint, aiming at understanding how the presence of a communication channel may fundamentally constrain the tracking performance. For multi-input multi-output systems, we also attempt to characterize an optimal strategy to allocate the powers of the individual channels to optimize the tracking performance. Additionally, by introducing a simple scaling factor, which may be interpreted as a simple scheme of joint channel and controller design, we show how the tracking performance may be improved.

Han-Fu Chen

Title: Stochastic Methods for Seeking Consensus of Networked Agents

Abstract: The talk starts with discussing the updating algorithms proposed in M. Y. Huang and J. H. Manton, Coordination and consensus of networked agents with noisy measurements: stochastic algorithms and asymptotic behavior, SIAM J. Control Optim. Vol. 48, No. 1, 134-161, 2009" (abbreviated as HM).
To solve the problem stated in HM a root-seeking approach is introduced in the talk. It is demonstrated that by this approach a stronger result can be obtained under weaker conditions by a much simpler proof in comparison with HM.
Further, the conditions guaranteeing convergence of the general root-seeking algorithm called the stochastic approximation algorithm with expanding truncations (SAAWET) are described. Then it is shown how to apply SAAWET to solve various problems arising from systems and control.

Fang Haitao

Title: Convergence Properties of Some Networked Systems with Noisy Observations

Abstract: In this talk, the consensus problem of multi-agents systems with noisy observations is considered. Some convergence results for networked systems with time-varying connect topology are presented. These results are given separately in the discrete time and continuous time situations with different noise conditions.

Wang Xiaofan

Title: Flocking Control with a Fraction of Informed Agents

Wang Long

Title: Complex Networked Systems and Beyond

Abstract: Some discussions on recent theoretic development for complex networked systems are presented, including network dynamics, multi-agent systems, collective behavior, swarm intelligence, artificial life, distributed optimization, robot network, intelligent traffic systems, evolutionary game dynamics, experimental economics, distributed sensor networks, cloud computing, and cyber-physical systems.

Guanrong Chen

Title: Pinning Control of Complex Network Synchronization

Abstract: In this talk, topics on complex network synchronization and its pinning control are presented. First, the concept of synchronization and some criteria are introduced for various dynamical networks, including fully-connected, ring-shaped and star-shaped regular networks, as well as small-world and scale-free complex networks. Then, the issue of pinning-controlled synchronization is discussed, for networks that do not satisfy self-synchronized conditions. Furthermore, some commonly concerned questions are addressed, such as what kind of controllers to deploy, how many to use, and where to apply them on the network, so as to achieve effective synchronization. Finally, a simple method is described for designing the state-feedback pinning controller gains, verified and visualized by numerical simulation examples.

Xinping Guan

Title: Wireless Networking Theory and Application

Abstract: Wireless communications and networking technologies have experienced a rapid evolution in the past two decades. Because of the intrinsic characteristics of wireless sensor networks and ad hoc networks such as energy limitation, multi-hop transmission and interference channel, resource allocation and congestion control are critical networking issues in collaborative and competitive environments. In this talk, the cross-layered optimization problem of joint congestion control, random access and power control is introduced based on game theory. Cognitive radio has widely drawn attention as a key technology to enhance spectrum efficiency. Some key techniques of cognitive radio networks are introduced and are developed to the applications in industrial wireless networks and emergency networks.

Zhang Huanshui

Title: New Estimator and Duality of Control for Multiplicative Noise Systems with Applications to Packet Dropping and Multiple Input Delay Systems

Abstract: In this paper, we propose a new linear estimator for multiplicative-noise systems by defining an innovation under a new criteria index. With the proposed estimation approach, we present a novel derivation for the stochastic LQ controller and show that the stochastic LQ control is fitly dual to the predictor defined in this paper, and from which we convert a more complicated problem of stochastic control for multiplicative noise systems with multiple input delays into a smoothing and filtering estimate problem. As the applications of the proposed new estimator, we also propose as novelestimator with packet dropping.

Weizhou Su

Title: Optimal Tracking and Tracking Performance Constraints from Quantization

Abstract: This paper studies the tracking performance of linear time-invariant (LTI) single-input single-output (SISO) discrete-time networked feedback systems. We take a step signal as system's reference into consideration, and assume that the output of controller is first quantized and then transmitted through a communication network to the remote plant, whereas the quantization error is modeled as product of a white noise and the input of quantizer. The tracking performance of the system we interested in is defined as the minimum mean square error between the output of the plant and the reference input. In this paper, two typical structures of networked control system are considered and we derive two explicit expressions of the best attainable tracking performance. The results provide fundamental performance bounds achievable using quantized control, demonstrating how the tracking performance may be constrained by the plant nonminimum phase zeros and the quantization precision. In addition, we obtain the sufficient and necessary condition to guarantee second-order stochastic input-output stability of quantized control system. Other than these, we present an output feedback design for a linear system with a multiplicative noise which is used to model the networked system in this work.

Zhi-Hong Guan

Title: Tracking Performance Limitations: From Classical Control Systems to Networked Control Systems

Abstract: In the past years, there has been much attention devoted to the study of intrinsic performance limits achievable by feedback control. One of the well-studied problems is optimal reference tracking. Lately, there has been increasing interest in the study of control systems in which non-ideal data transmission occurs, typically in the framework of

networked control systems. In this talk, we shall give a brief introduction and review on the researches in tracking performance limitations for the classical control systems. Then, we try to establish a framework of investigating these issues in the spirit of networked control systems. Our recent results will be given as illustration examples, which contain tracking of random signal, tracking under additive white Gaussian noise effect and tracking under both disturbance rejection and control energy constraint. Results show that communication constraints from networks take extra degree of restrictions on the tracking performance limitation.