ERCIM Fellowship Scientific Report

Fellow: Prasanna Chaporkar
Visited Location: INRIA, Paris, France
Duration of Visit: 9 Months
Supervisor: Prof. Francois Baccelli

1 Scientific Activity

Broadly, the focus of research in the first term of the fellowship was *mathematical modeling and performance analysis of wireless networks*. In particular, I have studied following two problems in collaboration with various researchers from INRIA, Paris, France and University of Pennsylvania, Philadelphia, PA, USA.

1.1 Distributed Scheduling in Wireless Networks

We address the question of attaining stability and fairness guarantees through distributed scheduling in wireless networks. We consider a simple, local information based, distributed scheduling policy called *Maximal Scheduling*. We prove that maximal scheduling attains a guaranteed fraction of the maximum stability region. The guaranteed fraction depends on the interference constraints due to underlying physical and MAC layer protocols. We obtain the stability guarantees for general interference constraints in the wireless networks. We also design a fully distributed algorithm that combines a token generation scheme with maximal scheduling policy so as to attain max-min fair rates within the feasible region of maximal scheduling.

1.2 Throughput Optimization in Loss-tolerant Wireless Networks

With advances in coding theory, many techniques have emerged that allow the recovery of the lost information efficiently. Examples of the techniques that require only some fraction of the packets to be received correctly for error-free construction of the complete message include digital fountain and network coding. Moreover, real-time applications can tolerate some loss without much degradation of the quality perceived by the end user. The loss-tolerance can be used to enhance the stability region of the system and also to simplify certain network protocols. We characterize the stability (bounded mean queue length) of such systems and obtain policies that maximize the system throughput (the total number of packets received correctly at the receivers per unit time) while stabilizing the system.

2 Papers Published during the Term

1. Prasanna Chaporkar, Saswati Sarkar, "Utility Optimal Scheduling for General Reward States and Stability Constraint", Proceedings of IEEE Conference on Decision and Control and European Control Conference (CDC-ECC), 2005, Seville, Spain, December 12-15, 2005.

   Abstract: *We consider a queueing system with n parallel queues, which receives a reward for the service it provides. Our aim is to maximize the expected reward obtained per unit time (utility) while ensuring that the mean queue length in each of the queues is bounded (stability). We show that the optimal policy has counter intuitive properties because of the general reward states and stability constraint. For example, the greedy policy of serving a customer that fetches maximum reward need not be optimal. In addition, the optimal policy may belong to a class of non work-conserving policies. We obtain two different policies that attain the above optimality goal. The first policy arbitrates service randomly based on the current reward states and probabilities that depend on system statistics. The second policy arbitrates service deterministically based only on the queue lengths and the current reward states, and does not require any knowledge of the system statistics. The proposed policies are optimal in a large class of policies that includes off-line policies, which use knowledge of past, present and even future arrival and reward states in their decision processes.*

2. Saswati Sarkar, Prasanna Chaporkar, Koushik Kar, "Fairness and Throughput Guarantees with Maximal Scheduling in Wireless Networks," Proceedings of the 4th Workshop On Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks", Boston, MA, U.S., April 3-7, 2006.

   Abstract: *We investigate the fairness and throughput properties of a simple distributed scheduling policy, maximal scheduling, in the context of a general ad-hoc wireless network. We design a fully distributed algorithm that combines a token generation scheme with maximal scheduling policy so as to attain max-min fair rates within the feasible region maximal scheduling. We next present throughput guarantees of maximal scheduling that quantify the performance loss of each session due to*

the use of the local information based scheduling. We show that the performance loss for each session depends on the maximum "interference degree" in its neighborhood. We also demonstrate that the performance penalties can not be localized any further.

3. Prasanna Chaporkar, Koushik Kar, Saswati Sarkar, "Achieving Queue Length Stability Through Maximal Scheduling in Wireless Networks" (Invited Paper), Proceedings of Information Theory and Applications Inaugural Workshop, University of California, San Diego, February, 6-10, 2006.

   Abstract: *We address the question of achieving stability guarantees through distributed scheduling in wireless networks. We consider a simple, local information based, distributed scheduling strategy, maximal scheduling, and prove that it attains a guaranteed fraction of the maximum stability region. By considering the notion of queue length stability, we strengthen existing rate stability results for maximal scheduling. The queue length stability guarantees provided by maximal scheduling can differ across sessions, and depends on the "interference degree" in the two hop neighborhood of the session.*

4. Prasanna Chaporkar, Saswati Sarkar, "Stable Scheduling Policies for Maximizing Throughput in Generalized Constrained Queueing", Proceedings of IEEE INFOCOM 2006, Barcelona, Spain, April 23-29, 2006.

   Abstract: *We consider a class of queueing networks referred to as "generalized constrained queueing networks" which form the basis of several different communication networks and information systems. These networks consist of a collection of queues such that only certain sets of queues can be concurrently scheduled. Whenever a queue is scheduled for service, the system transmits a packet and receives a certain reward. Different rewards are obtained for transmitting packets from different queues, and furthermore, the reward obtained for serving a queue depends on the set of concurrently scheduled queues. We demonstrate that the dependence of the rewards on the schedules alter fundamental relations between performance metrics like throughput and stability. Specifically, maximizing throughput is no longer equivalent to maximizing the stability region; we therefore need to maximize the stability region; we therefore need to maximize one subject to certain constraints*

on the other. Since stability is critical for bounding packet delays and buffer overflow, we focus on maximizing throughput subject to stabilizing the system. We design provably optimal scheduling strategies that attain this goal by scheduling the queues for service based on the queue lengths and the rewards provided by different selections. The proposed scheduling strategies are however computationally complex. We subsequently develop techniques to reduce the complexity and yet attain the same throughput.

3 Attended Seminars, Workshops and Conferences

3.1 Attended Seminars

1. Stability, routing and congestion control Frank Kelly, Prof. University of Cambridge, UK
2. Power Control for Wireless Networks - An Overview and Some New Directions Nick Bambos, Prof. at Stanford (Dept. EECS)
3. On the stability of a queueing system with uncountably branching fluid limits Serguei Foss, Heriot-Watt University, UK
4. Information theory: recent advances and future challenges Venkat Anantharam, University of California, Berkeley, USA
5. Collaborative Adaptive Sensing of the Atmosphere Jim Kurose, University of Massachusetts, Amherst

3.2 Attended Workshops

1. EuroNGI Workshop on QoS and Traffic Control, ENS, Dec 7-9 2005
2. Avant-Premire INFOCOM, Thomson Paris Lab, April 13th 2006
3. Network Modeling Day, Ecole Normale Suprieure, May 5th 2006

3.3 Attended Conferences

1. IEEE Conference on Decision and Control and European Control Conference (CDC-ECC), 2005, Seville, Spain, December 12-15, 2005.