Publications

Journals

JA.1 **V. Kavitha**, E. Altman, "Continuous Polling Models and Application to Ferry Assisted WLAN" accepted at Annals of Operations Research.

JA.2 **V. Kavitha**, E. Altman, R. Elazouzi and R. Sundaresan "Opportunistic scheduling in cellular systems in the presence of non-cooperative mobiles" accepted at IEEE Trans. Information Theory.

JA.3 **Veeraruna Kavitha**, Sreenath Ramanath and Eitan Altman, "Spatial queueing for analysis, design and dimensioning of Picocell networks with mobile users", vol. 68, issue 8, pp.710-727, Elsevier Performance Evaluation , August 2011.

JA.4 Eitan Altman, Tamer Başar and **Veeraruna Kavitha**, "Adversarial Control in a Delay Tolerant Network", IEEE ComSoc MMTC E-Letter Special Issue on GameSec and Multimedia Security, June 2011.

JA.5 T. Banerjee, V. Sharma, **V. Kavitha** and A. K. JayaPrakasam, "Generalized Analysis of a Distributed Energy Efficient Algorithm for Change Detection", vol 10, pp. 91-101, IEEE Trans. on Wireless Communications, Jan 2011.

Papers published in International Conferences

IC.1 **Veeraruna Kavitha** "Continuous Polling with Rerouting and Applications to Ferry Assisted Wireless LANs", 5th International ICST Conference on Performance Evaluation Methodologies and Tools (ValueTools), Cachan, Paris, 2011.

IC.2 Eitan Altman, **Veeraruna Kavitha**, Francesco De Pellegrini, Vijay Kamble and Vivek Borkar, "Risk sensitive optimal control framework applied to delay tolerant networks", IEEE **InfoCom 2011**, Shanghai, China.

IC.3 **Veeraruna Kavitha**, Eitan Altman, Rachid Elazouzi, Rajesh Sundaresan, "Fair scheduling in cellular systems in the presence of noncooperative mobiles", In Proc. **InfoCom 2010**, San Diego, USA.

IC.4 Sreenath Ramanath, **Veeraruna Kavitha**, Eitan Altman, "Open Loop Optimal Control of Base Station Activation for Green Networks", accepted in **WiOpt** 2011.

IC.5 Sreenath Ramanath, **Veeraruna Kavitha**, Merouane Debbah, "Satisfying Demands in a Multicellular Network: An Universal Power Allocation Algorithm", accepted in **WiOpt** 2011.

IC.6 Eitan Altman, Tamer Başar and **Veeraruna Kavitha**, "Adversarial Control in a Delay Tolerant Network", T. Alpcan, L. Buttyan, and J. Baras (Eds.): GameSec 2010, LNCS 6442, pp. 87-106.

IC.7 **Veeraruna Kavitha** and Eitan Altman, "Analysis and Design of Message Ferry Routes in Sensor Networks using Polling Models", IEEE Proceedings of the 8th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (**WiOpt**), pp. 247 - 255, May 31-Jun 04 2010, Avignon, France.

IC.8 Sreenath Ramanath, **Veeraruna Kavitha** and Eitan Altman, "Spatial queuing analysis for mobility in pico cell networks", IEEE Proceedings of the 8th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (**WiOpt**), pp. 152 - 159, May 31-Jun 04 2010, Avignon, France.

IC.9 Sreenath Ramanath, **Veeraruna Kavitha**, Eitan Altman, "Impact of mobility on call block, call drops and optimal cell size in small cell networks", IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops (PIMRC Workshops), pp. 157-162, 26-30 Sept. 2010, Istanbul, Turkey.

IC.10 **Veeraruna Kavitha**, Eitan Altman, "Opportunistic Scheduling of a Message Ferry in Sensor Networks", Proceedings of the Second International Workshop on Mobile Opportunistic Networking (MobiOpp) 2010, Pisa, Italy.

IC.11 **Veeraruna Kavitha**, Eitan Altman, Rachid Elazouzi, Rajesh Sundaresan, "Opportunistic scheduling in cellular systems in the presence of noncooperative mobiles", Proceedings of 48th IEEE **Conference on Decision and Control (CDC)**, pp. 8581 - 8587, 15-18 Dec. 2009, Shanghai, China.

IC.12 Essaid Sabir, Rachid El-Azouzi, **Veeraruna Kavitha**, Yezekael Hayel and El-Houssine Bouyakhf, "Stochastic Learning Solution for Constrained Nash Equilibrium Throughput in Non Saturated Wireless Collision Channels", 3rd ICST/ACM International Workshop on Game Theory in Communication Networks, GameComm 2009, Pisa, Italy.

IC.13 **Veeraruna Kavitha**, Eitan Altman, "Queueing in Space: design of Message Ferry Routes in sensor networks", 21st International Teletraffic Congress (ITC 21) 2009, Paris, France.

IC.14 Sreenath Ramanath, Eitan Altman, Vinod Kumar, **Veeraruna Kavitha**, Laurent Thomas, "Fair assignment of base stations in cellular networks", 22nd World Wireless Research Forum (WWRF) Conference, May 5-7, 2009, Paris, France

IC.15 T. Benerjee, **V. Kavitha** and V. Sharma, "Energy Efficient Change Detection over a MAC using Physical Layer Fusion", 33rd IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), pp. 2501 - 2504 , March 31 2008-April 4 2008, Las Vegas, USA.

IC.16 **V. Kavitha** and V. Sharma, "Tracking Analysis of an LMS Decision Feedback Equalizer for a Wireless Channel", 13th European Wireless Conference, Paris, France, April 2007.

IC.17 **V. Kavitha** and V. Sharma, "Analysis of an LMS Linear Equalizer for Fading Channels in Decision Directed mode", 13th European Wireless Conference, Paris, France, April 2007.

IC.18 **V. Kavitha** and V. Sharma, "Tracking performance of an LMS-Linear Equalizer for fading channels", 44th Annual Allerton Conference on Communication, Control and Computing, USA, September 2006.

IC.19 **V. Kavitha** and V. Sharma, "LMS versus Wiener filter for a Decision Feedback Equalizer", 44th Annual Allerton Conference on Communication, Control and Computing, USA, September 2006.

IC.20 **V. Kavitha** and V. Sharma, "Comparison of training, blind and semiblind equalizers in MIMO fading systems using capacity as measure", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP '05), 18-23 March 2005 , pp. 589-592, USA.

IC.21 **V. Kavitha** and V. Sharma, "Information theoretic comparison of training, blind and semiblind signal separation algorithms in MIMO systems", International Conference on Signal Processing and Communications, 2004. SPCOM '04, 11-14 Dec. 2004, pp. 407 - 411, Bangalore, India.

IC.22 Amaranada Reddy, Archana Nayak, Gurucharan, **Veeraruna Kavitha**, Sreenath Ramanath, "Implementation of a Multi-Channel Baseband CDMA Receiver on a ADSP2189M Processor", International Digital Signal Processing Conference 2001, Boston, USA.

Details of Contributions

Theoretical Results

The theoretical part of my research lead to the following three results. The last two results were obtained during my PhD tenure under the guidance of Prof. Vinod Sharma while the first result is obtained recently and solely by me. Some discussion with Eitan Altman were very helpful for the first topic.

T.1 Theoretical Performance of variety of Continuous polling systems is obtained using discretization approach, wherein the known Pseudo conservation laws of the discrete polling systems are utilized. These results depend heavily upon the fixed point analysis of infinite dimensional spaces and on the properties of Riemann-Stieltjes integrals.

T.2 A new ODE (ordinary differential equation) approximation theorem is obtained for stochastic approximation algorithms in which some components may depend upon two previous values. A second order ODE is shown to approximate the iterative algorithms.

T.3 Differentiability of stationary density of parametrized general state space Markov chains is obtained with respect to the parameter in L_2 norm. This result was useful in obtain the DFE based result.

Contributions towards Wireless Communication Systems

WC.1 **Risk Sensitive control of Delay Tolerant Networks ([IC.2]):** Users demanding data transfers, can tolerate delays and this fact is utilized to design cost effective and simple wireless networks, called Delay tolerant Networks (DTNs). Here the message is spread across all the contacted (relay) users and it spreads like epidemics till it reaches the destination. The control of such dynamics has thus gained a central role in all of these areas. The classical objective function in DTNs, i.e., the successful delivery probability of a message within a given deadline, takes often the form of the expectation of the exponent of some integral cost. So far, models involving such costs have been solved by interchanging the order of expectation and the exponential function. While reducing the problem to a standard optimal control problem, this interchange is only tight in the mean field limit obtained as the population tends to infinity. We identify a general framework from optimal control in finance, known as risk sensitive control, which allows us to handle the original (multiplicative) cost and obtain solutions to several novel control problems in DTNs. New optimal control problems which consider the effect of wireless propagation path loss factor and the power constraints at the source and or the destination are proposed for DTNS. The possibility of non-threshold type optimal policies is established for some of the control problems.

WC.2 Adversarial Control in a Delay Tolerant Network ([J.4, IC.6]):

We consider a multi-criteria control problem that arises in a delay tolerant network with two adversarial controllers: the source and the jammer. The objective of the source is to choose transmission probabilities so as to maximize the probability of successful delivery of some content to the destination within a deadline. These transmissions are subject to interference from a jammer who is a second, adversarial type controller. We solve three variants of this problem: (1) the static one, where the actions of both players, are constant in time; (2) the dynamic open loop problem in which all policies may be time varying, but are independent of state, the number of already infected mobiles; and (3) the dynamic closed-loop feedback policies where actions may change in time and may be specified as functions of the current value of the state (in which case we look for feedback Nash equilibrium). We obtain some explicit expressions for the solution of the first game, and some structural results as well as explicit expressions for the others. An interesting outcome of the analysis is that the latter two games exhibit switching times for the two players, where they switch from pure to mixed strategies and vice versa.

WC.3 Continuous Polling models ([JA.1, IC.1]): We focus on a class of polling systems encountered while modeling a class of ferry based wireless local area networks (FWLAN). A polling system is a queuing system with multiple queues that are attended by a common server. A system in which arrivals can occur in a continum of space is called a conitnuous polling system.

A ferry facilitates local communication between the nodes (or users) as well as the communication between the nodes and a base station (BS) that serves as the gateway to the external world. The ferry, while walking in a predetermined cyclic path, communicates with the static nodes of the network via a wireless link. The ferry is assumed to stop and communicate with a node that has a packet to send or to receive, when it is closest to that node. The location distribution of the node to which (or from which) a packet arrives is assumed to have a support of positive Lebesgue measure. These features imply that polling models with finite number of queues cannot be used to model the system. Further, in almost all studied continuous polling systems, the user leaves the system after his service is completed. But for every local data transfer, the ferry has to collect the data from the source and then deliver the same to the sink. It either delivers the data to the sink on its own or has to be guided by the BS for the same. Thus each transfer may require services at two or three independent locations. Such an application can be modeled by polling systems with rerouting. We study the continuous polling models with rerouting, via discretization approach and by using the known Pseudo conservation laws of discrete systems. We obtain its stationary expected workload as the limit of the same for a discrete system. Our results rely heavily on fixed point analysis of infinite dimensional operators. We also consider continuous polling models which support mixture of services.

WC.4 **Ferry based Wireless LANs ([JA.1,IC.7, IC.13, IC.10,IC.1]):** We study Ferry based Wireless Local Area Networks (FWLAN), in which a number of isolated nodes are scattered over some area. In FWLANs, the communication between a node and the outer world or the communication between any two nodes, is made possible via a message ferry. The Ferry has a predetermined cyclic path which collects messages from a node and delivers messages to it when it is in the vicinity of the node. We use the mathematical theory of polling systems to study the performance of the FWLAN. We consider three different architectures and each one of them is mapped to an appropriate polling system. The polling disciplines that are needed for modeling the FWLAN involve non-standard variants of gating disciplines. Our goal is to design the routes of the Ferry as well as the points where it should stop to distribute and collect messages. This mathematical modeling brings another dimension to the classical related vehicle routing problem due to the radio channel: the cyclic path of the ferry need not touch every node. The distance between the node and the ferry at the point when communication occurs determines the transmission rate and hence the service time and thus the systems capacity.

WC.5 **Satisfying Demands in a Multicellular Network: An Universal Power Allocation Algorithm ([IC.5]):** Power allocation to satisfy user demands in the presence of large number of interferers in a multicellular network is a challenging task. Further, the power to be allocated depends upon the system architecture (for example upon components like coding, modulation, transmit precoder, rate allocation algorithms, available knowledge of the interfering channels, etc). This calls for an algorithm via which each base station in the network can simultaneously allocate power in a decentralized way to their respective users so as to meet their demands (when they are within the achievable limits), using whatever information is available of the other users. The goal of our research is to propose one such algorithm which in fact is universal: the proposed algorithm works from a fully co-operative setting to almost no co-operation (becomes completely decentralized) and or for any configuration of modulation, rate allocation, etc. schemes. The algorithm asymptotically satisfies the user demands, running simultaneously and independently within a given total power budget at each base station. Further, it requires minimal information to achieve this: every base station needs to know its own users demands, its total power constraint and the transmission rates allocated to its users in every time slot. We formulate the power allocation problem in a system specific game theoretic setting, define system specific capacity region and analyze the proposed algorithm using ordinary differential equation (ODE) framework. Simulations confirm the effectiveness of the proposed algorithm.

WC.6 **Opportunistic and Fair scheduling in the presence of noncooperative mobiles ([IC.3,JA.2,IC.11])**

A centralized dynamic scheduling decision has to be made by a Base station to fair share the resources, based on the current channel gains signaled by the mobiles. But the mobiles can be non-cooperative, they may signal erroneously to improve their own utilities. We first study the case of efficient scheduling, i.e., the case with $\alpha = 0$. This non cooperative scheduling is well captured by a Signaling Game : (1) Mobiles (lead players) : Signal the BS of their channel value. (2) BS (follower) : Makes a scheduling decision using the signals. (3) Scheduling decision determines the payoff for all mobiles, BS. We found that this Signaling game admits only babbling equilibria : (1) Mobile's strategy, signal regardless of its channel. (2) BS's strategy, ignore the signals from mobiles. Thus, desired *separating* Perfect Bayesian Equilibrium (PBE) does not exists !! We then propose various approaches to enforce truthful signaling of the radio channel conditions: an approach based on some knowledge of the mobiles' policies, and an approach that replaces this knowledge by a stochastic approximations approach that combines estimation and control. We further identify the other equilibria that involve non-truthful signaling.

It is not possible to model alpha fair non-cooperative scheduling, with $\alpha > 0$, as a Signaling game. Nevertheless, using general non-cooperative game theoretic framework, we showed that there exists only NE, which resemble the babbling equilibria. However, as $\alpha \to \infty$, the existing alpha fair schedulers can resist the non-cooperative behavior to a better extent. We then propose robust alpha fair schedulers which induce truth revealing NE as is done in the case of efficient schedulers ($\alpha = 0$). These robust schedulers require additional knowledge; that of the cooperative shares of the users (the average throughputs obtained by users under truthful signaling).

WC.7 **Spatial Queuing theory to model mobility in pico cell based networks ([JA.3,IC.8,IC.9]):** In this work, we characterize the performance of small cell networks in the presence of moving users. We model various traffic types between base-stations and mobiles as different types of queues. We derive explicit expressions for expected waiting times, service times and drop/block probabilities for the various queuing models considered for both fixed as well as random velocity of mobiles. We obtain (approximate) closed form expressions for optimal cell sizes when the velocity variations of the mobiles is very small for both data as well as voice calls. We conclude from the study that, if the call is long enough, the optimal cell size depends mainly on the velocity profile of the mobiles, its mean and variance. It is independent of the traffic type or duration of the calls. Further, for any fixed power of transmission, there exists a maximum velocity beyond which successful communication between the mobile and the system is not possible. This maximum possible velocity increases with the power of transmission. Also, for any given power, the optimal cell size increases when either the mean or the variance of the mobile velocity increases.

WC.8 **Energy Efficient Nash Equilibrium for Non-saturated Collisions channels ([IC.12]):** We consider a shared uplink in the form of a non saturated collision channel, where a users's transmission can be successful only if no other user attempts transmission simultaneously. Packets are scheduled for retransmission if there is a collision. We study this in a noncooperative framework: each user has a fixed throughput demand and it dynamically adapts its transmission probability in order to obtain its required demand. We noted that the region of equilibria is larger than the saturated case and showed the existence of infinite number of Nash equilibria. In addition to providing an energy efficiency analysis, characterizing the Energy Efficient Equilibrium (EEE), we proposed a fully distributed algorithm which converges to the EEE.

WC.9 **Wireless Equalizers ([IC.16,IC.17,IC.18,IC.19,IC.20,IC.21]):**While studying a decision feedback equalizer (DFE), whose minimum mean square error (MMSE) solution is not known: a) the closed form expression used in many practical systems, obtained by neglecting the decision errors, is shown to be far away from the true MMSE equalizer. b) Least Mean Square (LMS) filter, used actually as a computationally less complex alternative, is shown to converge close to the true MMSE equalizer. c) LMS filter is further shown to track the MMSE equalizer in a wireless medium using the second order ODE approximation results. We further obtain the tracking analysis of Linear equalizers, tracking a wireless medium and in training mode as well as decision directed mode, once again using the second order ODE approximation results.

WC.10 **Global Position System([IC.22]):**While designing Global Position System receivers at ACCORD, lot of research was involved to make the algorithms work in real field. The findings of this research led to further research and development while designing high data rate CDMA links intended for Mission control applications, using similar design techinques as in GPS.