Laxminarayana S Pillutla

Education

05/2009	**Ph. D. (Electrical and Computer Engineering)** University of British Columbia (UBC), Vancouver, BC, Canada Dissertation title: Resource Management in Wireless Networks
05/2004	**M. S. (Electrical Engineering)** Wichita State University, Wichita, KS, USA Thesis title: Capacity of MIMO Systems – A Theoretical and Practical Perspective
05/2000	**B. E. (Electrical and Electronics Engineering)** University of Madras, Chennai, TN, India

Research Interests

- ***Applied:*** PHY, MAC and cross layer design aspects of wireless networks with current focus on mmWave communication networks, wireless sensor networks, cognitive radio networks and vehicular networks.
- ***Theoretical:*** Statistical signal processing, information theory, optimization theory, game theory, stochastic geometry **(tools from these areas form the basis for analysis in the applied areas mentioned above)**.

Research Accomplished

April 2009 – present: Associate Professor (Assistant Professor till August 2016), Dhirubhai Ambani Institute of Information and Communication Technology (DA-IICT), Gandhinagar, Gujarat.

- **Angles of arrival and departure estimation in mmWave networks:** In this research we considered the problem of angle of arrival (AoA), angle of departure (AoD) and the concomitant channel estimation problem for millimeter wave communication systems. Specifically, we proposed a pilot based integrated channel acquisition and tracking scheme. This is a work in progress and our future work in this domain shall aim to devise better AoA, AoD and channel estimation schemes by leveraging the sparse nature of channel at mmWave frequencies. In a related work we also obtained Bayesian CRLB for AoA, AoD and multipath gain estimation in mmWave networks.

  This work is in joint collaboration with Dr. Ramesh Annavajjala, Affiliate Research Associate Professor at Northeastern University, Boston, MA, USA.

- **Directional MAC protocols for mmWave networks:** Nodes in mmWave networks would be based on directional antennas in which coordination among user nodes would take precedence over interference management. In our research we have proposed adaptive learning based directional MAC protocols whose performance was observed to be superior to that of the conventional directional MAC protocols proposed in the literature.

  Group size: 3 (myself – team leader, one M.Tech. student and one B.Tech. Student)**.**

- **Indoor target tracking using wireless sensor networks (WSNs):** We considered distributed tracking of targets in an indoor environment using WSNs based on RSSI measurements. To improve tracking accuracy an incremental estimator based on EM algorithm is used. Tracking of targets is accomplished using a particle filter based algorithm. For information exchange among nodes, to facilitate distributed implementation of target tracking algorithm, random linear network coding is used. The entire implementation was done using a combination of MATLAB and Jprowler (an open source network simulator). Specific MATLAB toolboxes used include Statistics and Optimization.

  Group size: 3 (myself – team leader, one M.Tech. student and one B.Tech. Student)**.**

- **Spectrum sensing in cognitive radio networks:** As part of this research we considered two problems: (i) Selection of secondary users for cooperative spectrum sensing. For this purpose an algorithm based on discrete stochastic optimization is proposed that can adapt to the dynamic nature of radio environment. (ii) Spectrum sensing with multiple antennas under the quickest change detection framework. Simulation of both these works were done in MATLAB.

  Group size: 3 (myself – team leader and two M.Tech. students).

- **Network coding (NC) in relay based wireless networks:** In this research we considered performance of relay based wireless networks with PHY layer NC. Specifically, we considered the performance of decode and forward with joint modulation (DF-JM) at relay nodes with power allocation and relay selection. OFDM was assumed to be the PHY layer transmission mechanism to combat the frequency selective nature of the channel. Our simulation results show that the throughput achieved with DF-JM scheme to be much higher than what we would get with the simple DF scheme. Further the results also demonstrate that the DF-JM scheme, with equal power allocation across various relay nodes outperforms the case in which the best relay is selected. This is in contrast to what was observed in the case of amplify forward (AF) scheme, in which the relay selection combined with optimal power allocation gave higher throughput values than the scheme in which all relays transmit with optimal power allocation.

The validation of the proposed scheme was done in MATLAB. Specific MATLAB toolboxes used include Communications and Digital Signal Processing. Our implementation of OFDM included channel estimation using a scattered pilot pattern.

Group size: 2 (myself – team leader, one M.Tech. student and one B.Tech. student)**.**

September 2004 – December 2008: Research Assistant, University of British Columbia, Vancouver, BC, Canada.

- **Node cooperation and distributed source coding in sensor networks:** In this research we considered combination of node cooperation based on space-time block codes (STBC) and distributed source coding to improve energy efficiency of sensor networks. Through our simulation results in MATLAB we noted that node cooperation and distributed source coding improve energy efficiency of sensor networks. Further node cooperation between various sensor nodes achieves better energy-mutual information trade off than the scheme in which there is no node cooperation among nodes.

  The optimization problem formulation and proving of various theoretical results in the work was done by me under the able guidance of my PhD supervisor.

- **Amelioration of DCF operation in IEEE 802.11 WLANs:** The DCF mechanism used in IEEE 802.11 networks suffers from a performance anomaly due to low rate users in the network. The low rate users in the network occupy the channel for inordinately large amount of time thereby depriving other users from their fair share to transmit on the channel. This results in a dramatic decrease in the overall network throughput. In this research, we employ price based approach to guarantee “time-based fairness” across all the network users by ensuring that all the users transmit at certain minimal rates. The interaction between various decentralized WLAN users is analyzed under a non-cooperative game theoretic framework. Our simulation results demonstrate the improvement in overall network throughput with appropriate tuning of the price.

  The problem formulation and analysis was done by me with timely guidance from my PhD supervisor. The simulations in MATLAB were completely done by me.

- **Performance of TCP in cognitive radio networks under dynamic spectrum access:** In this work we considered the performance of TCP under the paradigm of dynamic spectrum access, in which unlicensed users access the spectrum opportunistically. This kind of opportunistic access by unlicensed users can induce a new type of loss known as “service interruption loss” from licensed users of the underlying spectrum. Our simulation results in NS2 (an open source C/C++ network simulator) suggest that there exists an optimal number of channels that

the unlicensed users need to capture to maximize their TCP throughput, which is unlike what happens in conventional networks that do not allow dynamic spectrum access.

The simulation testbed in NS2 was created by me and a postdoctoral fellow under the guidance of our supervisor.

- **Study and simulation of Statistical Signal Processing Algorithms:** As part of this research we considered study of the following techniques/algorithms namely: (i) Deterministic and stochastic least squares, (ii) Hidden Markov Model (HMM) filter, (iii) Kalman filter, (iv) Particle filter and (v) Expectation Maximization (EM) algorithm. An important aspect of the understanding process involved simulation of random variables/processes and implementation of above mentioned algorithms in MATLAB.

  The work was done individually by me under the guidance of my PhD supervisor.

August 2001 – May 2004: Research Assistant, Wichita State University, Wichita, KS, USA.

- **Information-theoretic capacity of MIMO and MIMO-OFDM systems:** In this work we considered information theoretic capacity of the following two cases: (i) In this case we considered capacity of MIMO antenna systems under the assumptions of Rayleigh flat fading and channel state information available at both the transmitter and receiver. In an earlier work it was shown that the capacity can be achieved by performing water-filling across space and time domains. In this work we came up with closed form expression for rates that can be achieved using two sub-optimal adaptive transmission schemes namely: channel inversion and truncated channel inversion. We also computed upper bound on the (ergodic) capacity of a MIMO system in which receiver alone has access to the channel state information. As an aside we also gave a formula to compute the various moments of an unordered eigen value of the central Wishart distribution. (ii) In this case we investigated the capacity of a MIMO-OFDM system under spatial correlation in multi-path environment in which one of the paths corresponds to a direct line-of-sight (LoS) component (modeled according to a Ricean distribution), while the other correspond to specular components (modeled according to a Rayleigh distribution). Our simulation results in MATLAB suggest that the presence of a LoS component, in general, leads to a reduction of the ergodic capacity of the underlying MIMO-OFDM system.

  The problem formulation and the computation of closed form expressions were done by me under the guidance of my MS thesis supervisor.

- **Simulation of IS 95 system in MATLAB:** In this research we simulated the bit error rate performance of an IS 95 up link and down link in MATLAB. The salient features of the work are as following: (i) implementation of interleaver and de-interleaver for the FEC block, (ii) implementation of Walsh and short PN spreading of various channels and (iii) implementation of RAKE receiver. For the FEC purpose we used convolution codes and Viterbi decoder was used for decoding purposes at the receiver. The various MATLAB toolboxes used for this purpose include Communications and Signal Processing.

  This work was done by me under the guidance of my MS thesis supervisor.

Publications

Journals/Book Chapters:

1. L. S. Pillutla, "Network Coding Based Distributed Indoor Target Tracking Using Wireless Sensor Networks," Springer Journal on Wireless and Personal Communications, in press (url: http://rdcu.be/pOEf).
2. L. S. Pillutla and V. Krishnamurthy, "A Price based Approach to Decentralized Rate Selection in IEEE 802.11 WLANs," Springer Journal on Wireless and Personal Communications, February 2011, vol. 56, no. 2, pp. 517-534.
3. L. S. Pillutla, T. Issariyakul and V. Krishnamurthy, "Tuning Radio Resource in an Overlay Cognitive Radio Network for TCP: Greed Isn't Good," IEEE Communications Magazine, July 2009, vol. 47, no. 7, pp. 57-63.
4. L. S. Pillutla and V. Krishnamurthy, "Data Gathering in Correlated Wireless Sensor Networks with Cooperative Transmission," in Cooperative Communications for Improved Wireless Network Transmission, IGI-Global Publications, Editors: M. Uysal, 2008 (**invited**).
5. Q. Pang, L. S. Pillutla, V. C. M. Leung, and V. Krishnamurthy, "Impact of Cognitive Radio Links on Upper Layer Protocol Design," in Cognitive Radio Networks, Auerbach Publications, CRC Press, Editors: Y. Xiao and F. Hu, 2008 (**invited**).

Conference papers:

1. L. S. Pillutla and R. Annavajjala, "Bayesian CRLB for Joint AoA, AoD and Multipath Gain Estimation in Millimeter Wave Wireless Networks", to appear in Globecom 2017, Singapore.
2. L. S. Pillutla and R. Annavajjala, "Integrated Acquisition and Tracking Scheme for Channel Estimation in Millimeter Wave Wireless Networks", to appear in PIMRC 2017 Montreal, Canada.
3. P. Tiwari, D. Meena and L. S. Pillutla, "Adaptive Learning Based Directional MAC Protocol for Millimeter Wave Wireless Networks", to appear in PIMRC 2017, Montreal, Canada.
4. L. S. Pillutla and B. Joshi, "Sequential Cooperative Spectrum Sensing in Cognitive Radio Networks: Optimal Selection of Secondary Users and Their Spectral Measurements", in proceedings of COMSNETS 2017.

5. L. S. Pillutla, S. Gupta, and D. Singh, “Impact of Network Coding on Distributed Indoor Target Tracking using Wireless Sensor Networks,” in proceedings of WPMC 2015, December 13-16, 2015, Hyderabad, India.
6. L. S. Pillutla, S. J. Ahir, and N. Patel, “Selection of Secondary Users for Cooperative Spectrum Sensing in Cognitive Radio Networks using Discrete Stochastic Optimization,” in proceedings of SPCOM 2014, July 22-25, 2014, IISc., Bangalore.
7. L. S. Pillutla and V. Krishnamurthy, “Game Theoretic Rate Adaptation in Spectrum-Overlay Cognitive Radio Networks,” in proceedings of IEEE Global Communications Conference (Globecom), 2008.
8. L. S. Pillutla and V. Krishnamurthy, “Mutual Information and Energy Tradeoff in Correlated Wireless Sensor Networks,” in proceedings of IEEE Conference on Communications (ICC), 2008.
9. L. S. Pillutla and V. Krishnamurthy, “Minimum Energy Data Gathering in Correlated Wireless Sensor Networks with Cooperative Transmission,” in proceedings of IEEE Conference on Communications (ICC), Glasgow, Scotland, June 2007.
10. L. S. Pillutla and V. Krishnamurthy, “Structural Results on Optimal Rate and Number of Clusters in Cooperative MIMO Sensor Networks,” in proceedings of IEEE Asilomar Conference on Signals, Systems and Computers, Monterey, CA, USA, November 2005.
11. L. S. Pillutla and V. Krishnamurthy, “Joint Rate and Cluster Optimization in Cooperative MIMO Sensor Networks,” in proceedings of IEEE Conference on Signal Processing Advances in Wireless Communications (SPAWC), New York, NY, USA, June 2005.
12. L. S. Pillutla and S. K. Jayaweera, “Capacity of MIMO Systems in Rayleigh Fading and Shadowing,” in proceedings of IEEE Asilomar Conference on Signals, Systems and Computers, Monterey, CA, USA, November 2004.
13. L. S. Pillutla and S. K. Jayaweera, “Capacity of MIMO Systems in Rayleigh Fading with Sub-Optimal Adaptive Transmission Schemes," in proceedings of IEEE International Symposium on Information Theory and its Applications (ISITA) 2004, Parma, Italy, October 2004.
14. L. S. Pillutla and S. K. Jayaweera, “MIMO Capacity of an OFDM-based System under Ricean Fading,” in proceedings of IEEE Vehicular Technology Conference (VTC), Milan, Italy, May 2004.

Technical Reports:

1. CRLB Calculations for Joint AoA, AoD and Multipath Gain Estimation in Millimeter Wave Wireless Networks. (Document no: arXiv: 1704.00453), available at https://arxiv.org/abs/1704.00453.

Works in progress:

1. S. Mudliar and L. S. Pillutla, “Performance Evaluation of Memory Guided Directed Medium Access Control (MAC) Protocol in the Presence of Relays”, submitted to IEEE ANTS 2017.
2. L. S. Pillutla and S. Baghel, “Relay Based Wireless Networks with Joint Modulation, Power Allocation and Relay Selection”, submitted to IEEE ANTS 2017.

Research Grants

Completed:

- "Wireless Telemedicine using Body Area Sensor Networks and Heterogeneous Access Networks", funded by Department of Science and Technology (DST), Govt. of India, under the fast track scheme for young scientists (total amount approved: Rs. 12.6 Lacs).

Book Reviews

- Reviewed the monograph: "Algorithms and Models for Network Data and Link Analysis" by F. Fouss, M. Saerens and M. Shimbo, publisher: Cambridge University Press. The review was published by Computing Reviews (Review #: CR145528 and publication date: September 08, 2017).
- Reviewed the monograph: "Signals and Systems: A Primer with MATLAB" by M. Sadiku and W. Ali, publisher: CRC Press Inc. The review was published by Computing Reviews (Review #: CR145298 and publication date: May 25, 2017).
- Reviewed the monograph: "Sequential Analysis: Hypothesis Testing and Changepoint Detection" by A. Tartakovsky, I. Nikiforov and M. Basseville, publisher: Chapman & Hall/CRC. The review was published by Computing Reviews (Review #: CR143654 and publication date: July 27, 2015).
- Reviewed the monograph: "Statistical Methods for Ranking Data" by M. Alvo and P. Yu, publisher: Springer. The review was published by Computing Reviews (Review #: CR143481 and publication date: May 29, 2015).
- Reviewed the monograph: "Information and Control in Networks" edited by G. Como, B. Bernhardsson and A. Rantzer, publisher: Springer. The review was published by Computing Reviews (Review #: CR143202 and publication date: February 23, 2015).
- Reviewed the monograph: "Algorithmic Probability and Friends: Bayesian Prediction and Artificial Intelligence" edited by David L. Dowe, publisher: Springer. The review was published by Computing Reviews (Review #: CR142391 and publication date: June 12, 2014).
- Reviewed the monograph: "Fundamentals of Signals and Systems, SIE", by Michael J Roberts, Tata McGraw Hill.

Select Presentations

- "Statistical Signal Processing", CEP course conducted for ISRO-SAC Scientists at DA-IICT, Gandhinagar, from March 8th to 12th , 2016.
- "Optimal Filtering and Parameter Estimation Techniques for Statistical Models", tutorial delivered at International Symposium on WPMC 2015, Hyderabad, India on December 13th, 2015.
- "An Overview on Cognitive Radio", as part of a short term training program (STTP) held at G H Patel College of Engineering and Technology (GCET), V V Nagar, Gujarat, on May 21st, 2014.
- "Indoor Target Tracking using Wireless Sensor Networks", Group Monitoring Workshop organized by Department of Science and Technology (DST), Bangalore, April 26th, 2013.

- A Price based Decentralized Rate Selection for IEEE 802.11 WLANs, delivered at IIT-Delhi (on September 14th, 2011) and IIT-Hyderabad (on September 22nd, 2011).
- "Wireless Standards – 3G to WiFi," presented at IETE Zonal Seminar on GenNext Wireless Technologies and Network Security, Ahmedabad, February 21st, 2010.
- "Minimum Energy Data Gathering in Correlated Wireless Sensor Networks with Cooperative Transmission", ICC 2007, Glasgow, Scotland, June 2007.
- "TCP Performance Optimization in Wireless Networks under Dynamic Spectrum Access (DSA)", second UBC-IEEE Workshop on Future Wireless Systems, Vancouver, BC, March 2007.

Teaching

Postgraduate level:

- Advanced Wireless Communications
- Statistical Estimation Theory
- Information Theory and Coding
- Advanced Digital Communications
- Detection and Estimation Theory

Undergraduate level:

- Computer Networks (includes design and instruction of lab experiments based on NS2).
- Analog and Digital Communications (includes design and instruction of lab experiments based on LABVIEW).

Research Mentoring

M.Tech. Students Supervision:

- Mr. Mayank Dubey; Thesis title: "Cooperative Spectrum Sensing via Dynamic Scheduling of Secondary Users" (Date of completion: August 2017).
- Ms. Arti Bhanushali ; Thesis title: "Digital Implementation of Orthogonal Frequency Division Multiplexing (OFDM)". (Date of completion: May 2017).
- Mr. Deep Tandel (joint supervision student); Thesis title: "Low Power ASIC Implementation of SC-FDMA". (Date of completion: May 2017).
- Mr. Digant Doshi ; Thesis title: "Energy Efficient Data Gathering in Wireless Sensor Networks". (Date of completion: May 2017).
- Mr. Harshit Pratik (joint supervision student); Thesis title: "ASIC Implementation of STBC Based MIMO-OFDM System". (Date of completion: May 2017).
- Ms. Pooja Tiwari; Thesis title: "Adaptive Learning Based Directional Medium Access Control Protocol for Millimeter Wave Communication". (Date of completion: May 2017).
- Ms. Sonal Bagel; Thesis title: "Physical Layer Network Coding in Relay Assisted OFDM based Wireless Networks". (Date of completion: June 2016).
- Ms. Shweta Mudliar; Thesis title: "Distributed Medium Access Control (MAC) Protocol at 60 GHz for Outdoor Wireless Networks". (Date of completion: June 2016).
- Mr. Dushyant Singh; Thesis title: "Application of Network Coding in Wireless Sensor and Relay based Ad Hoc Networks". (Date of completion: July 2015).

- Ms. Sara Barmal; Thesis title: “Spectrum Sensing in Cognitive Radio using Quickest Change Detection Framework”. (Date of completion: July 2015).
- Mr. Sagar Ahir; Thesis title: “Spectrum Sensing in Cognitive Radio Networks” (Date of completion: June 2014).
- Mr. Sanjay Keshvala; Thesis title: “Indoor Target Tracking using Wireless Sensor Networks” (Date of completion: June 2013).

Work Experience

September 2016 – to date	**Associate Professor**, Dhirubhai Ambani Institute of Information and Communication Technology (DA-IICT), Gandhinagar, Gujarat, India.
April 2009 – August 2016	**Assistant Professor**, Dhirubhai Ambani Institute of Information and Communication Technology (DA-IICT), Gandhinagar, Gujarat, India.
June 2000 – July 2001	**Project Engineer**, M/S. Windson Power Controls and Systems Private Limited.

Awards and Professional Service

- Visiting Researcher, Department of Electrical Engineering, IIT-Bombay, **May-June, 2012**.
- Postdoc at University of Toronto worth (CA$42,000) **(did not take it up, instead joined DA-IICT, Gandhinagar)**.
- Recipient of full tuition fee waiver for PhD study at the University of British Columbia.
- Served as reviewer for major IEEE Journals (Transactions on Signal Processing, Signal Processing Letters, and Communication Letters), and Conferences (ICC, ICASSP, SPAWC, Globecom).
- Member, DA-IICT's M.Tech. curriculum review committee (MTCRC)-2017.
- Member, IEEE.
- Instrumental in drafting the intellectual property rights (IPR) policy at DA-IICT.
- Member, executive council, DA-IICT Centre for Entrepreneurship and Incubation (DCEI) **(from September, 2010 – May, 2015)**.

References

- Available upon request.