The Academic and Industrial Embrace of Space–Time Methods

Every episode of the classic 1966–1969 television series *Star Trek* begins with Captain Kirk's (played by William Shatner) famous words : "Space: The final frontier … ." While *space* may not be the *final* frontier for the information and communication theory community, it is proving to be an important and fruitful one.

In the information theory community, the notion of *space* can be broadly defined as the simultaneous use of multiple, possibly coupled, channels. The notions of *space–time* and *multiple-input multiple-output* (MIMO) channels are therefore often used interchangeably. The connection between space and MIMO is most transparent when we view the multiple channels as created by two or more spatially separated antennas at a wireless transmitter or receiver.

A large component of the current interest in space–time methods can be attributed to discoveries in the late 1980s and early 1990s that a rich wireless scattering environment can be beneficial when multiple antennas are used on a point-to-point link. We now know that adding antennas in a rich environment provides proportional increases in point-to-point data rates, without extra transmitted power or bandwidth.

The promise of big rewards for successful space–time or MIMO modulation and coding design methods started a flood of research from the academic and industrial communities that continues today. Traditional codes that were designed as one-dimensional streams in time and that achieved rates close to the channel capacity with low error probability, are now being reworked into codes that can achieve capacity on this more complex MIMO channel, and at channel capacities much higher than their scalar channel counterparts. Much of current research focuses on channel modeling and measurement, and on the design of modulation and coding techniques that are two-dimensional, covering both space and time. Researchers with backgrounds in engineering, physics, and mathematics are contributing alike.

We are also reforming our ideas of what constitutes unwelcome corruption and interference on a channel. The corruptions that originate from unknown fluctuations in the channel, from interfering users, or from additive noise at the receiver are generally considered detrimental. In multichannel communications, another form of corruption results when signals from one channel couple into another. As we now know, this form of corruption can sometimes be used to advantage, especially in multiple-antenna wireless systems where the coupling accounts for a large part of the capacity gain over single-antenna systems.

Early research has resulted in the acceptance of some fledgling MIMO techniques into the third-generation cellular standards both in the United States and Europe. There is widespread belief that IEEE 802.11 (WiFi) systems will benefit from space–time techniques. Academic research activities span the range from group theory to random matrix theory to packings in Grassman manifolds. Furthermore, with advancements in space–time or MIMO research comes the realization that some wireline communications systems might also benefit from MIMO research advances. For example, digital subscriber line (DSL) circuits, where twisted pairs of cables run in close proximity over long distances, exhibit coupling between the pairs. Multimode fiber-optic cables have coupling between their modes.

This Special Issue contains papers from various subareas under the broad space–time umbrella. Ten papers are dedicated to two-dimensional space–time code designs, covering various aspects including block and trellis codes.

Seven papers consider Shannon-theoretic aspects of point-to-point MIMO. Six papers are dedicated to the recent discoveries that many of the point-to-point capacity benefits of multiple antennas in a rich scattering environment carry over to a multiuser environment. A base station or access point with multiple antennas can communicate with a set of users, each with one antenna. The resulting sum-capacity grows with the number of users and antennas at the base station.

Five papers look at noncoherent and differential space–time methods, where neither the transmitter nor the receiver knows the matrix channel between them. Noncoherent methods are viewed as candidates for rapidly changing mobile environments, where there is little time for training to learn the channel.

Two papers examine stochastic aspects of a matrix-valued channel, three look at beamforming in a scattering environment, and two look at algorithmic and complexity issues related to coding.

As this Special Issue shows, academic and industrial research in space–time methods is still vibrant, and the field continues to pose appealing problems to applied and theoretical engineers, physicists, and mathematicians.

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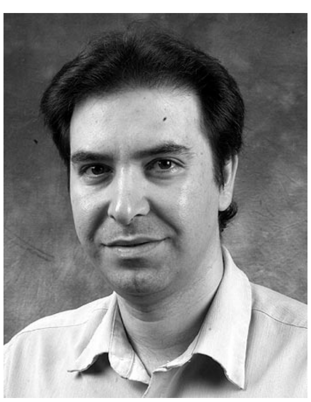
From 1986 to 1989, he worked for the Department of Defense at Fort Meade, MD. During 1995–1996, he was a Research Associate and Visiting Assistant Professor at the Coordinated Science Laboratory, University of Illinois, Urbana-Champaign. He joined the Mathematics of Communications Research Department at Lucent Technologies, Bell Laboratories, Murray Hill, NJ, in September 1996. He is now a Distinguished Member of the Technical Staff. His professional interests include communications and information theory, probability theory, and statistical signal processing.

Dr. Hochwald is the recipient of several achievement awards while employed at the Department of Defense and the Prize Teaching Fellowship at Yale. He served as a Guest Editor for the IEEE TRANSACTIONS ON SIGNAL PROCESSING Special Issue on "Signal Processing Techniques for Space–Time Coded Transmissions."

Giuseppe Caire (S'91–M'94–SM'03) was born in Torino, Italy, on May 21, 1965. He received the B.Sc. degree in electrical engineering from Politecnico di Torino, Torino, Italy, in 1990, the M.Sc. degree in electrical engineering from Princeton University, Princeton, NJ, in 1992, and the Ph.D. degree from Politecnico di Torino in 1994.

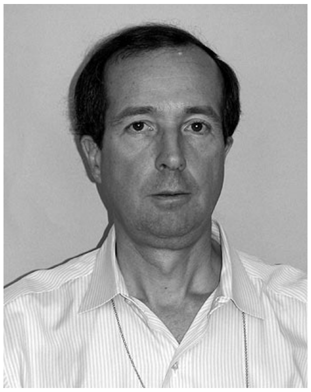
He was with the European Space Agency (ESTEC, Noordwijk, The Netherlands, in 1995 and has been visiting the Institute Eurecom, Sophia-Antipolis, France, in 1996 and Princeton University in summer 1997. He was Assistant Professor in Telecommunications at the Politecnico di Torino and presently is Professor at the Mobile Communications Laboratory of the Eurecom Institute. He is coauthor of more than 50 papers in international journals and more than 80 in international conferences, and is the author of several international patents. His professional interests are focused on digital communications theory, information theory, coding theory, and multiuser detection, with particular focus on wireless terrestrial and satellite applications.

Prof. Caire was a recipient of the AEI G.Someda Scholarship in 1991, the COTRAO Scholarship in 1996, and a CNR Scholarship in 1997. He served as Associate Editor for the IEEE TRANSACTIONS ON COMMUNICATIONS during 1998–2001 and since 2001 has been Associate Editor for Communications of the IEEE TRANSACTIONS ON INFORMATION THEORY. In 2003. he received the Jack Neubauer Best System Paper Award of the IEEE Vehicular Technology Society.



Babak Hassibi was born in Tehran, Iran, in 1967. He received the B.S. degree from the University of Tehran in 1989, and the M.S. and Ph.D. degrees from Stanford University, Stanford, CA, in 1993 and 1996, respectively, all in electrical engineering.

From October 1996 to October 1998, he was a Research Associate at the Information Systems Laboratory, Stanford University, and from November 1998 to December 2000, he was a Member of the Technical Staff in the Mathematical Sciences Research Center at Bell Laboratories, Murray Hill, NJ. Since January 2001, he has been an Assistant Professor of Electrical Engineering at the California Institute of Technology, Pasadena. He has also held short-tem appointments at Ricoh California Research Center, the Indian Institute of Science, and Linköping University, Sweden. His research interests include wireless communications, robust estimation and control, adaptive signal processing, and linear algebra. He is the coauthor of the books *Indefinite Quadratic Estimation and Control: A Unified Approach to H^2 and H^∞ Theories* (Philadelphia, PA: SIAM, 1999) and *Linear Estimation* (Englewood Cliffs, NJ: Prentice-Hall, 2000). He is a recipient of an Alborz Foundation fellowship, the 1999 O. Hugo Schuck best paper award of the American Automatic Control Council, the 2002 National Science Foundation CAREER Award, and the 2003 Okawa Foundation Research Grant for Information and Telecommunications.



Thomas L. Marzetta (S'76–M'77–SM'93–F'03) was born in Washington, DC. He received the Ph.D. degree in electrical engineering from the Massachusetts Institute of Technology, Cambridge, in 1978. His dissertation extended the three-way equivalence of autocorrelation sequences, minimum-phase prediction error filters, and reflection coefficient sequences to the two-dimensional case.

He worked for Schlumberger-Doll Research from 1978 to 1987 to modernize geophysical signal processing for petroleum exploration. From 1987 to 1995, he performed research and development at Nichols Research Corporation under contracts from the U.S. Department of Defense, NASA, and Schlumberger; he headed a group that improved automatic target recognition, radar signal processing, and video motion detection. Since 1995, he has been with Bell Laboratories (formerly AT&T, now Lucent Technologies), currently in the Mathematical Sciences Research Center, Murray Hill, NJ, where he heads the Mathematics of Communications Research Department. He specializes in multiple-antenna wireless with particular emphasis on techniques for realizing extremely high throughputs with large numbers of antennas.

Dr. Marzetta is a member of the Sensor Array and Multichannel Technical Committee of the IEEE Signal Processing Society, and he has served as Associate Editor for two IEEE journals, and as Guest Editor for the IEEE TRANSACTIONS ON SIGNAL PROCESSING Special Issue on Signal Processing Techniques for Space–Time Coded Transmissions. He was the recipient of the 1981 ASSP Paper Award from the IEEE Signal Processing Society. He was elected a Fellow of the IEEE in January 2003.