ECE 792-055 Space-Time Communication Theory

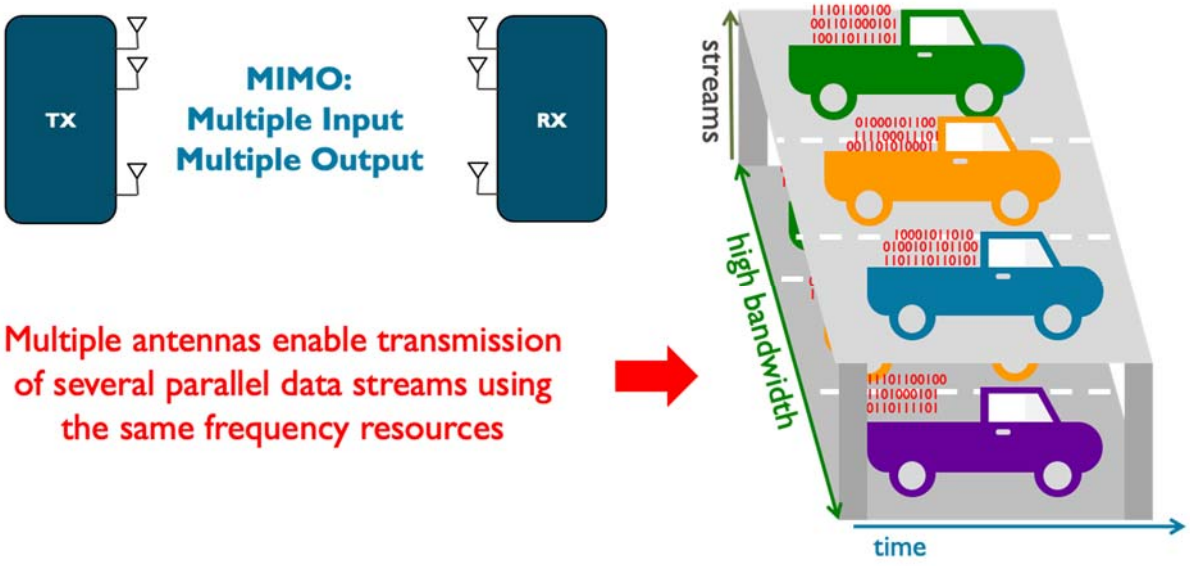
Instructor(s): Robert W. Heath Jr., Lampe Distinguished Professor, rwheathjr@ncsu.edu

Objective or Description: Space is truly the final frontier in wireless communication systems. When leveraged correctly, the use of multiple antennas at the transmitter and / or the receiver, create a propagation channel with additional spatial degrees of freedom that can be exploited to improve the quality, capacity, and coverage - problems faced by all wireless systems. In this class you will learn the fundamentals of space-time communication from the perspective of communication and information theory. The emphasis will be on MIMO (multiple-input multiple-output) communication systems where antenna arrays are used at both transmitter and receiver. The class covers the fundamentals as well as a several advanced topics.

Prerequisites: The main prerequisite knowledge for this course is an understanding of wireless digital communications, as obtained for example from EE 592-094 Signal Processing and Deep Learning for Advanced MIMO, other courses, or through your own research on wireless related topics. Knowledge of and comfort with random processes (ECE 514 or equivalent) is essential. Familiarity with linear algebra and working with matrices will be important. We will use tools from information theory, but all the essentials are covered in this course; no prior background is required.

Textbook: R. W. Heath, Jr. and A. Lozano, *Foundations of MIMO Communication*, Cambridge University Press, 2019.

Topics:



- Mathematical fundamentals like entropy, mutual information, random matrix theory and linear minimum mean squared error estimation
- MIMO signal and channel models including MIMO-OFDM
- Single antenna, single user communication including the capacity of AWGN and fading channels
- Single user MIMO with optimum receivers including the power constraints, capacity and pilot-assisted communication
- Multi-user communication principles and rate regions
- Multiple user MIMO communication with optimum receivers including the MAC and broadcast channels
- Multiple user MIMO communication with linear receivers
- Massive MIMO communication
- Special topics which might include MIMO from a circuits perspective, distributed MIMO, cell-free massive MIMO, and mmWave / THz MIMO

Grading:

- 30% Assignments including homework, project related work, and class participation
- 20% Midterm exam
- 20% Final exam
- 30% Final project (literature review, conference paper, or journal paper on a topic related to the course)

Instructor background:

Robert W. Heath Jr. is the Lampe Distinguished Professor in the Dept. of Electrical and Computer Engineering at the North Carolina State University. Previously he was the Cockrell Family Regents Chair in Engineering #7 at The University of Texas at Austin. In 2011, the IEEE Board of Directors elevated him to IEEE Fellow for "contributions to multiple antenna wireless communications", their highest level of membership. In 2017, he was elected as a Fellow of the National Academy of Inventors, which recognizes academic inventors who have demonstrated a prolific spirit of innovation in creating or facilitating outstanding inventions that have made a tangible impact on quality of life, economic development, and the welfare of society. He was an elected Distinguished Lecturer in the IEEE Signal Processing Society and the IEEE Vehicular Technology Society. He is also an amateur radio operator and a registered Professional Engineer in Texas.

He has considerable real-world engineering experience, including working at a wireless startup in Silicon Valley, running a consulting company **MIMO Wireless Inc,** and co-founding a local startup Kuma Signals LLC. He has consulting with many companies around the world and is on the technical advisory board of two startup companies.

His approximately 600 publications are among the most cited in wireless communications and signal processing. He has published four books: *Millimeter Wave Wireless Communications* (a book on the theory and practice of wireless communications at high frequencies), *Digital Wireless Communication: Physical Layer Exploration Lab Using the NI USRP* (a laboratory book on signal processing for wireless communications), *Introduction to Wireless Communications: A Signal Processing Perspective* (an undergraduate text targeted towards teaching wireless communications to undergraduates), and *Foundations of MIMO Communication* (a textbook that presents an information theoretic view of multiple antenna wireless systems).

He is among the most highly cited researchers in Computer Science and Electronics, with a rank of 49 worldwide and 34 in the USA http://www.guide2research.com/scientists. He is among the top cited research in wireless communications and signal processing. His papers have received numerous awards including the 2010 and 2013 EURASIP Journal on Wireless Communications and Networking best paper awards, the 2012 Signal Processing Magazine best paper award, a 2013 Signal Processing Society best paper award, the 2014 EURASIP Journal on Advances in Signal Processing best paper award, the 2014 Journal of Communications and Networks best paper award, the 2016 IEEE Communications Society Fred W. Ellersick Prize, the 2016 IEEE Communications Society and Information Theory Society Joint Paper Award, the 2019 IEEE Communications Society Stephen O. Rice Prize, the 2019 IEEE Kiyo Tomiyasu Award, and the 2020 IEEE Signal Processing Society Donald G. Fink Overview Paper Award. He is was an elected member-at-large of the IEEE Signal Processing Society Board of Governors, and currently serves as an elected member-at-large of the IEEE Communications Society Board of Governors.

Outside of teaching, Prof. Heath is interested in stand up jetskis (where he has built two custom carbon fiber skis), scuba diving, and exploring Galicia in Spain. He is also a Private Pilot, though has not been flying recently.