Research Highlight – Shrinivas Kudekar

All my research papers have been published in internationally reputed conferences and journals, which have a stringent, anonymous, peer review process, judging scientific importance, originality and clarity of exposition. My major research accomplishment in the field of information science is via the very recent work ***threshold saturation via spatial coupling*** ([1, 2, 3, 4, 5, 6, 7, 8]).

Introduction to Information Science

Communication is an indispensable part of daily human life. Examples of communication devices include mobile phones, Internet or telephone networks. With these systems we communicate messages across the world. Other examples of communication devices include DVDs, iPods, hard disk drives. These electronic devices store digital data and can then be "replayed" at any point of time.

Any communication channel is *inherently noisy*. This means we can never transmit information perfectly. Random signal fluctuations are the characteristic of all electrical circuits. These corrupt our information. For example, the signal from the mobile phone is distorted due to interference from other phones, buildings or trees. Sometimes playing back music or video from a DVD might not be perfectly possible if there is a scratch or dust on the DVD. The field of information science, and more specifically coding theory, makes it possible to communicate digital information *reliably* across any noisy media such that the original information can be retrieved.

In his seminal paper on *mathematics of communications* in 1948, Claude Shannon, formulated a theory of digital communication which forms the basis of all modern communication systems. Shannon introduced the notion of *capacity of a noisy channel*: we can remove the channel errors and recover the information perfectly as long as we are transmitting at speeds smaller than the capacity of the channel. If we transfer above the capacity of the communication channel, the receiver will not be able to remove the errors introduced by the channel no matter how sophisticated it is. In other words, one can think of the *capacity as a fundamental limit of communication across any noisy media.*

The goal of coding theory is to develop techniques, called as "error-correcting codes", which allow us to communicate information reliably over noisy channels. In more technical terms, the transmitter (your mobile phone) *encodes* the information message in a *codeword*. The codeword protects the message against the noise of the communication channel. At the receiver, the codeword is then *decoded* to retrieve the original information message. Every communication device has limited computational and energy resources due to their size. Thus the key point of coding theory now is to develop codes that are not complex, so that they can be easily implemented in our electronic devices. This is a hard problem and it is only fairly recently, around 1995 - 2000, that a combined effort of coding theorists, mathematicians, computer and electrical engineers has resulted in invention of codes that allow us to do so.

My Main Research Contribution: Spatially Coupled Codes

As the demand for faster communication increases, the dream of transferring information near the Shannon capacity remains elusive. Thus the ultimate goal would be to develop encoders and decoders which are *fast* and we are able to communicate *reliably* at the capacity, that is, we are communicating as fast as possible. This has been a long standing open problem and my main research contribution, presented in [1], has made significant progress to solve this. In our research article we study a particular class of codes known as "spatially coupled codes". We formulate a general mathematical theory, which we call as **threshold saturation via spatial coupling**. Using this theory we show that these codes can be used to transmit information at speeds extremely close to the Shannon capacity, using encoders and decoders which are very fast and easy to implement. We also show that these codes are universal: they can be used without knowing the exact nature of the noisy channel. *Thus, we show that spatially coupled codes hold the tremendous promise of achieving simultaneously the dream of transmitting at Shannon's limit, practical implementability and universality.* Spatially coupled codes thus stand to fundamentally alter the design of communication devices by making them smaller, faster and more reliable.

Apart from the practical significance of these codes in design of digital communication systems, our theory of threshold saturation is being used currently to design systems and analyze problems in computer science, signal processing and statistical physics. Thus our research has generated interest across many scientific disciplines. After the publication of our work [1], an *entire session has been devoted to spatially coupled codes* at the Information Theory and Applications (ITA) conference held once every year at the University of California at San Diego, USA, (`http://ita.ucsd.edu/workshop/11/talks/`). This is a premier conference in communications which is attended by over *500 researchers across academia and industry throughout the world* with focus not only on the theoretical aspects but also on various important applications like bioinformatics, medical imaging and cyber security. Also an *entire workshop on spatially coupled codes* was held at the Tokyo Institute of Technology, Japan, (`http://www.comm.ss.titech.ac.jp/`) and will be held at the École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, (`http://caact.epfl.ch/index.php/Workshop`). These workshops will be attended by all the top coding theorists and computer scientist in the world.

References

[1] Shrinivas Kudekar, Tom Richardson, Rüdiger Urbanke, *Threshold Saturation via Spatial Coupling: Why Convolutional LDPC Ensembles Perform so well over the BEC.* In IEEE Transactions on Information Theory, 2010.

[2] Shrinivas Kudekar, Tom Richardson, Rüdiger Urbanke, *Achieving Capacity via Belief Propagation.* In preparation.

[3] Shrinivas Kudekar, Kenta Kasai, *Threshold Saturation on Channels with Memory via Spatial Coupling.* Submitted to IEEE International Symposium on Information Theory (ISIT), Saint-Petersburg, Russia, 2011.

[4] Shrinivas Kudekar, Kenta Kasai, *Spatially Coupled Codes over the Multiple Access Channel.* Submitted to IEEE International Symposium on Information Theory (ISIT), Saint-Petersburg, Russia, 2011.

[5] Shrinivas Kudekar, Tom Richardson, Rüdiger Urbanke, *Threshold Saturation via Spatial Coupling: Why Convolutional LDPC Ensembles Perform so well over the BEC.* In the proceedings of IEEE International Symposium on Information Theory (ISIT), Texas, U.S.A, 2010.

[6] Shrinivas Kudekar, Cyril Measson, Tom Richardson, Rüdiger Urbanke, *Threshold Saturation on BMS Channels via Spatial Coupling.* In the proceedings of IEEE 6th International Symposium on Turbo Codes and Iterative Information Processing, France, 2010.

[7] Shrinivas Kudekar, Henry Pfister. *The Effect of Spatial Coupling on Compressive Sensing.* In Forty-Eight Annual Allerton Conference on Communication, Control and Computing, 2010, Illinois, U.S.A.

[8] Shrinivas Kudekar, Kenta Kasai, *Spatial Coupling for Nonnegative Compressive Sensing.* In preparation.