Massive MIMO: Prototyping, Proof-of-Concept and Implementation

Malkowsky, Steffen

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Wireless communications has become a major part of every day life. Ever since the first smart-phone released the number of application and use cases exploded. Streaming music, watching news or high-definition movies, chatting on messenger apps or just simply browsing the internet while being "on the road", is it on the bus, on the train or simply while sitting in a waiting room has become every day routine. This tremendous growth will certainly continue as other applications such as smart homes, driverless cars, connected industry etc. becoming more common. Whether it is a camera in your house you are connecting to, your fridge telling you that you ran out of milk or a machine at work notifying you that it needs new material, the number of applications are endless. On the downside all these applications producing data traffic are bringing the current 4G wireless technologies and the data rates supported to its limits, and as we are progressing towards the "internet of everything" connecting more and more devices together, new technologies are required. Since the frequency bands for wireless communications are very crowded, not leaving much space for extension, these new technologies have to deliver higher efficiency to provide more data and more connectivity while still being reliable within the same frequency band. One of these technologies, also incorporated in the recently released 5G standard is massive MIMO. Simply speaking, massive MIMO scales up the number of the antennas on the base station by a factor of 10 or even more, thereby being able to steer data beams with very high accuracy towards the required user.

While massive MIMO has shown superior performance over 4G in theoretical analyses, a proper evaluation also includes practical implementation aspects in order to verify that the heavily increased complexity is manageable. As massive MIMO enforces the usage of significantly more antennas on the base-station side there are plenty of challenges to overcome. Those include distribution of processing units, implementation of signal processing in order to actually "communicate" but also mechanical challenges of assembling a system of such dimensions. Moreover, theoretical promised performance must also be investigated in real-life scenarios. While theoretical analysis often relies on simplified models in order to keep a problem solvable, only real-life measurements can capture all the environmental influences on a system. Therefore, a functioning prototype is capable of providing the actual proof that a proposed technology fulfills its promises in real-life applications. Additionally, experiences of prototyping may be transformed to actually move a design onto integrated circuits. Here, cost, power consumption, performance and flexibility are some of the main implementation aspects. Flexibility may be achieved by providing a programmable platform which allows to adapt to the still evolving 5G standard.

This thesis focuses around exactly these topics of prototyping, real-life evaluation and on-chip integration of massive MIMO. It presents an in-depth discussion of the first real-time massive MIMO testbed prototype and provides insights on how the tremendous complexity challenge and data moving problem was solved using off-the-shelf hardware and proper design distribution. Furthermore, measurement campaigns were conducted to prove the benefits of utilizing massive MIMO in 5G systems, both with static and mobile users. These test showed that massive MIMO indeed is capable of living up to its promises delivering multiple times higher data rates as compared to 4G. Finally, a programmable processor specifically trimmed for massive MIMO algorithms was designed. Run-time and implementation analysis suggests that the proposed architecture achieves high performance while still remaining fully programmable with a relatively low power consumption.