Reciprocity Calibration for Massive MIMO

Mots clés :
- Directeur de thèse : dirk SLOCK
- Co-encadrant(s) :
- Unité de recherche : Laboratoire de recherche d'EURECOM
- Ecole doctorale : École Doctorale Informatique, Télécommunications, Électronique de Paris
- Domaine scientifique principal : Divers

Résumé du projet de recherche (Langue 1)
Context Multi-user multiple-input multiple-output (MU-MIMO) systems offer big advantages over conventional point-to-point MIMO: they work with single antenna user terminals and they do not require a rich scattering environment. The number of users that can be served concurrently is less or equal to the number of antennas used. Massive MIMO takes MU-MIMO to the next level by scaling up the number of antennas at the base station by an order of magnitude, providing additional degrees of freedom in the channel. These additional degrees of freedom can be used to design more simple and scalable signal processing algorithms and help focusing energy into small regions of space and thus reducing interference. However, these algorithms require channel state information at the transmitter (CSIT). Due to the large number of antennas, acquisition of CSIT is not feasible through feedback (the channel would be outdated by the time it is measured and fed back). Therefore a time-division duplexing (TDD) approach that exploits the channel reciprocity seems much more feasible. While very attractive in theory, in practice it is not so easy to achieve due to the non-reciprocal nature of the hardware. Eurecom has been working on the topic of channel reciprocity for some years now with some significant results: [4,5,8,11,12,13,16,17,18]. Recently we have also started to develop a massive MIMO platform based on our established OpenAirInterface platform. In its final stage the platform will feature 64 independently controllable RF chains built from 16 ExpressMIMO2 software radio cards. The goal of the platform is to carry out measurement campaigns to validate the feasibility of exploiting channel reciprocity in massive MIMO systems and to demonstrate massive MIMO real-time communication using the OpenAirInterface LTE software modem. State of the Art in Channel Reciprocity Calibration The symmetry of the electromagnetic propagation channel w.r.t. the exchange of the roles of the transmitter and receiver, or reciprocity, is often cited in the literature as a convenient way to obtain channel state information at the transmitter (CSIT) without requiring a feedback link. Indeed, if a single antenna is used, the channel is used in both directions using a reference. This results in known phase offsets at the receiver and the channel state information can be obtained from the received signals. In fact, whereas it is possible to come up with ingredients of these models analytically, reliable models can only be obtained by extracting them from measurement data. Moreover, such new models will require new estimation algorithms that need to be developed too. Last, but not least, another big challenge is the integration of the calibration procedures in a system context, where the channel representations are unknown and the effects of cross-talk and mutual coupling are neglected. This assumption is investigated experimentally in [18], where it is shown that the calibration matrix is indeed not diagonal, but at the same time the effects on some simple beamforming algorithms are negligible. Other practical applications of the relative reciprocity calibration are cognitive overlay systems such as presented in [9], [12], [13], [16], [17]. There the calibration is used to train a secondary cognitive overlay system. Challenges Massive MIMO relies to a great extent on the exploitation of channel reciprocity to gain channel state information at the transmitter (CSIT). However, while the physical radio channel is reciprocal, the effects of the radio frequency circuits is not and must be calibrated. The calibration itself relies on models of the hardware and the antennas and on the estimation algorithms. Today, no reliable models exist for the selectivity in time or frequency of the calibration factors, or for the mutual coupling and cross talk in large antenna arrays that model mutual coupling and cross talk exist. They thus need to be developed and tested using measurements. In fact, whereas it is possible to come up with ingredients of these models analytically, reliable models can only be obtained by extracting them from measurement data. Moreover, many new models will require new estimation algorithms that need to be developed too. Last, but not least, another big challenge is the integration of the calibration procedures in a system context, for example in 4G or 5G systems. Expected Results We expect to advance the state of the art in exploiting reciprocity in massive MIMO systems by (i) providing more accurate and experimentally validated models for the non-reciprocal hardware parts, (ii) developing calibration algorithms for the calibration parameters, and (iii) developing calibration procedures that can be integrated in 5G standards. The project will further provide a prototype architecture for a demonstrator that will control 64 active antenna elements from a common baseband engine, providing also calibration mechanisms for beam-forming, capability for digital beamforming and extensions to compliant with the LTE protocol stack. This will allow the two-way experimentation with a massive antenna array, testing and evaluating the different algorithms developed in this project. In order to assess the performance of the developed algorithms we will use the CSIT estimation error. As a baseline reference we will use CSIT estimation error achievable with an LTE Rel 10 FDD system employing transmission mode 9 with an 8 antenna element array and quantized feedback to estimate the CSIT. We expect 1) a significant improvement in terms of CSI accuracy after calibration, 2) and this with minimal calibration overhead by exploiting the proper models, and 3) also in the massive MIMO regime.

Résumé du projet de recherche (Langue 2)
Task planning T1: Study of the State of the Art

A number of literature pointers appear here already, but a more exhaustive search can be carried out. The relevant patents need to be studied also (e.g., Qualcomm, ArrayComm). Any channel calibration techniques or relevant channel estimation and feedback techniques in existing standards (LTE-A, Wi-Fi) would be useful reference points. Moreover, this literature study shall include the role of CSIT in massive MIMO applications to determine the required accuracy for scheduling and for precoding.

T2: Measurement campaign

Measurements are essential for the reciprocity modeling. It is conceivable though that the resulting model may depend on the particular hardware used. In the first phase of this task, we will carry out measurement campaigns with the Eurecom massive MIMO testbed and the Eurecom MIMO OpenAir Sounder (EMOS) software that will serve as an input for Task 3 and 4. In the second phase, we will carry out a second measurement campaign using the implemented calibration protocols and the beamforming algorithms to evaluate the feasibility of the developed ideas.

T3: Reciprocity Modeling and Estimation

Particular aspects that need to be studied for proper modeling are frequency-selectivity (beyond the phase shift introduced by differential delays due to unequal signal path lengths) and temporal variation (after removing the effects of clock drifts and carrier offsets). In the multiple antenna case, possible antenna coupling needs to be analyzed. The models will be derived from the measurements collected in Task 2. Further, optimal estimation techniques need to be developed, accounting for noise, errors, and the reciprocity model, especially in the multi-antenna case. In the MIMO case, a linearized version of the calibration model leads to Total Least-Squares type techniques. Various ways of fixing the scale factor for rendering the calibration model unique lead to different performances. The linearized model represents a straightforward variation at a given subcarrier, but may need to be looked at more closely in the case of frequency-selective (FIR) calibration factors.

T4: Reciprocity Calibration Protocols and Integration in 5G systems

The BS side calibration factors can be estimated from a link of the BS to any UE, as observed in [14], [15] but also earlier in [8]. The questions then become how to design protocols for the calibration operation, the feedback required, etc. We will further study the possibility of integrating the calibration protocols into existing and upcoming cellular standards, such as LTE Rel 12 or 5G. A second goal of this task is to propose extensions to the signaling formats of transmission mode 9 (8 stream multiuser-MIMO with precoding) or its successor to allow for more than 8 streams, in order to benefit from the additional spatial-multiplexing capabilities of a massive antenna array.