Advanced interference management in ARTIST4G: Interference Exploitation

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Abstract—This paper gives an overview of the objectives and current research activities on interference exploitation in the EC funded research project ARTIST4G. Focus is on channel estimation and multi-cell joint processing. First field trial results for different cooperation schemes are provided.

I. INTRODUCTION

Current state-of-the-art in standards has been largely driven by the goal to improve peak data rates and to get as close as possible to capacity limits. Higher-order modulation schemes, turbo-coding, HARQ, larger bandwidths and an increased number of antennas are means to push and virtually achieve those limits. Therefore, further improvements based on these means is coming to its limits. Moreover, improvements of peak data rates by these means does not necessarily lead to better user satisfaction because the received data rate depends heavily on the user location.

It is a major goal of the ARTIST4G project to investigate, evaluate, and disseminate solutions to pave the way for a balanced user experience with ubiquitous quality for everyone, irrespective of the user position in the cell.

One of the key topics in ARTIST4G is interference management, which can be further classified into two types:

1. Avoid interference at the receiver. This can be done by coordinating transmissions from different points to achieve orthogonality in time and frequency, or to mitigate interference through coherent or non-coherent precoding, in all cases leading to an increase in spectral efficiency.
2. Step back from the paradigm of avoiding or mitigating interference through transmitter-sided techniques, but instead allow for a certain extent of interference which can then be exploited at the receiver side.

The overall aim is to design a system that can perform soft-tuning between avoidance and allowance for interference. This paper presents the objectives and current status of the research work in ARTIST4G regarding interference exploitation. Interference avoidance is treated in a companion paper.

II. INTERFERENCE EXPLOITATION

By making use of cutting-edge receiver algorithms it is theoretically possible to perform interference cancellation and to turn intra-/inter-cell interference – which is nowadays a major limiting factor in cellular networks – into something harmless or even beneficial (cf., e.g., [1][2][3][4]).

An important aspect is how current and future systems can benefit from these concepts and the according algorithms, especially taking into account that an evolution path based on existing standards must exist [5]. In this respect, the concepts need to be properly evaluated, and their potential performance gains and the according challenges and requirements need to be investigated.

Based on those analytical findings it is the goal of ARTIST4G to exploit interference in the sense of allocating resources in the system such that interference can be cancelled efficiently. Depending on the receiver type it may be beneficial to raise interference power to detect and cancel it at the receiver side. It is the core idea of interference exploitation to take such properties into account in resource allocation. One of the main enablers for the aforementioned soft-tuning approach is physical layer abstraction designed to predict instantaneously the receiver’s performance with respect to its complexity. In this line of thought, a promising method was recently submitted to the ongoing Long Term Evolution (LTE) Advanced feasibility study in the third Generation Partnership Project (3GPP) [6] and is under consideration in ARTIST4G.

Future networks have to cope with even more diverse QoS requirements due to the tremendous increase in diverse data applications. Since interference in general strongly impacts the QoS of a transmission, it is an important challenge to design a more effective radio interface by designing flexible interference control mechanisms. With flexible interference control we mean to flexibly map data with different QoS requirements either on transmission streams using orthogonal transmission techniques or to map it to overlapping streams without aiming to avoid interference degradation during transmission. Thus, for the overlapping streams we allow for interference (from streams intended for another receiver) or even make use of it [7] (by transmitting data in multiple overlapping streams to the same receiver). The overlapping streams may belong to the same cell or to different cells (intra-/inter-cell interference).

In order to achieve its full potential, appropriate interference cancellation and exploitation needs to be
It has to be tackled from two sides:

1. Receiver algorithms working on the physical layer which cancel interference have to be investigated. Their performance and requirements concerning the interference situation need to be well understood.

2. Based on the findings on the receiver requirements concerning the interference situation, appropriate higher layer resource allocation schemes and respective control signalling have to be designed. It should be taken into account that constraints like receiver capabilities or latency requirements might put either interference avoidance or interference cancellation/exploitation in favour. A soft tuning between both allows for flexibility and should be taken into account. Cooperative concepts allowing for soft-tuning of inter-cell interference are to be addressed.

Both components must go hand in hand to perform well. As for the new algorithms to be developed current state-of-the-art link-to-system models cannot be applied, new models have to be derived [8].

### III. CHANNEL ESTIMATION

In LTE, as in other mobile communication systems, the accuracy of channel estimates seriously affects system performances, especially for advanced interference mitigation and exploitation schemes. In this section, we describe channel estimation approaches treated in ARTIST4G. The first part is dealing with general channel estimation based on cell-specific pilots and discusses some iterative approaches to improve the performance of conventional approaches. The second part focuses on advanced channel estimation for multi cellular mobile radio environments.

#### A. Iterative Channel Estimation

Among the existing solutions, the well known MMSE estimator has satisfactory performance but this comes with a high implementation complexity. Thus, some modified MMSE estimators are proposed to reduce the complexity (see, e.g., [10], [11], and references therein). Currently, the traditional 2x1D interpolation algorithm is commonly preferred because of its low implementation complexity. However, the degradation compared to perfect CSI is still large, for example about 3dB for a typical case as shown in Figure 1.

With the demanding requirements, more sophisticated approaches are needed to further improve the performance and approach the best achievable case. Therefore, more and more efforts are devoted to iterative channel estimation algorithms which are expected to give better performance with reasonable implementation complexity. Some possible approaches can be summarized as follows:

- Iterative 2x1D interpolation to improve performance of the simple 2x1D interpolation algorithm.
- Adopt Expectation-maximization (EM) channel estimation for OFDM [12] [13], to the LTE systems. Consider simplifications in order to reduce complexity and latency of EM channel estimation.
- Iterative channel estimation and MIMO equalization to account for sensitivity to channel estimation errors [14]
- Develop iterative joint channel estimation and detection over factor graphs for LTE systems [15].

![Figure 1: Bit error rate (BER) performance over ETU70 channel with MCS QPSK 1/3.](image)

#### B. Channel Estimation for Multi Cellular Radio Environments

For cellular radio environments, highest modulation and coding schemes (MCS) like 64QAM5/6 for LTE Rel.8 will have to be supported and will require a mean square error (MSE) for CSI estimation of >15-20dB. Note, non linear processing schemes might need even lower MSEs.

Strong frequency selectivity - specifically for cell edge UEs - demands for narrowband CSI estimation to achieve optimum performance for the envisaged precoding and advanced receiver processing schemes. LTE Rel.8 channel estimation allows estimation of up to 4 antenna ports (AP) based on a dense grid of so called common reference signals (CRS) [9]. Inter cell interference between CRSs of adjacent cells is very effectively reduced by cell specific Zadoff Chu sequences, which run in frequency domain over all subcarriers of the OFDM symbols and provide very good wideband - but limited narrowband – orthogonality due to the shortened sequence length.

One option is to add further orthogonality by applying well known techniques like time- frequency- or code domain multiplexing (TDM, FDM, CDM). There are pros and cons for each of the techniques, but the main issue is the exploding overhead for higher number of APs per cell and increasing number of cells, where typical values are 8 to 16 cells.

Currently for LTE Rel.10 additional so called CSI RS are evaluated for narrowband multi cell CSI estimation, being sparse in frequency and time. User specific DMRSs - precoded with the same precoder as the user data - are intended for transparent demodulation of jointly precoded user data. For CoMP there will have to be orthogonal DMRS for
each spatial layer, where for future CoMP schemes 8 or even more spatial layers can be expected.

One might easily end up with an overall overhead of 30%, for CRS, CSI RS plus DMRS, which motivates the analysis of more elaborated channel estimation concepts. Figure 2 illustrates the typical interference conditions for JP CoMP systems consisting exemplary of 2 eNBs serving two UEs UE1 and UE2. Demodulation reference signals RSx and RSy are transmitted with the same precoders W*V as the according data signals and are mutually orthogonal to each other. The block diagonal matrix V contains cell individual broadband beamformers – potentially selected from a codebook – which reduces the – potentially different per cell - number of antenna elements. W is the inter cell precoder matrix, which would be for zero forcing (ZF) the pseudo inverse of the effective channel matrix \( H_{\text{eff}} = H^*V \), i.e. \( W = (H^*V)^{-1} \). For perfect CSI estimation the interlayer interference \( I_{\text{ls}} \) will be zero. In case of CSI outdated, estimation or quantization errors there will be residual interference \( I_{\text{rs}} \). In the following two short options are given how this might be exploited:

- In case of precise precoding based on accurate CSI estimation one might avoid double estimation of the radio channel for CSI estimation and demodulation. The idea is to estimate received signal and inter stream interference \( I_{\text{ls}} \) based on orthogonal RSs RSx and RSy for each UE and to feedback this information to the eNBs. The central unit (CU) will than calculate the precoding correction matrix \( P = (H^*W^*V)^{-1} \), where ‘ indicates estimation based on RSx and RSy. In the following transmissions the CU will precode with \( P^*W^*V \) instead of \( W^*V \), thereby correcting the precoding errors. There will be strong scheduler implications as DMRS are only available on previously scheduled resources.

- If precoding accuracy is high - e.g. due to powerful CSI RSs – inter layer interference \( I_{\text{ls}} \) will be very low. In that case it looks promising to use spatial division multiplexing (SDM) for DMRS, i.e. to use same DMRSs for two or more UEs, thereby reducing overall overhead.

Further topics will be to investigate sparse in time DMRS for low mobility users as well as an integrated approach including CSI prediction.

IV. MULTI-CELL JOINT SIGNAL PROCESSING

In multi-cell joint signal processing multiple BSs jointly process the signals originating from multiple UEs transmitting on the same physical resource blocks (PRBs). For such schemes synchronization in time and frequency is required to avoid inter-symbol and inter-carrier interference and to obtain coherently overlapping received signals in frequency domain [22]. In general, two different joint signal processing strategies exist that have different implications w.r.t. the required backhaul infrastructure between BSs. A BS can either decode the data bits of an assigned UE and then forward these (or a quantized representation thereof) to another BS for interference subtraction [16][18]. Or a BS quantizes all received signals and forward these to another BS, where centralized joint detection takes place [17]. These strategies show a trade-off between cooperation gain and backhaul usage. It appears beneficial to dynamically adapt the cooperation strategy according to the current channel realization [19].

First field test comparison results of the two cooperation strategies have been obtained in the ARTIST4G large scale LTE-Advanced testbed in Dresden [20]. For this, a setup with 2 eNBs and 2 UEs was used as depicted in Figure 3. The UEs were moved along the indicated trajectory in order to generate a multitude of interference scenarios, ranging from symmetric cell-edge cases to asymmetric cases. A subset of results from this field trial is shown in Figure 4, where the maximum throughput of the two UEs is plotted against the backhaul required for cooperation. In the plot, squares denote UE 1, and circles UE 2, and we consider a symmetric cell-edge scenario with one antenna per UE and per eNB. The black markers on the left side indicate the reference case of LTE Rel. 8, where each BS individually decodes its assigned UE, hence without cooperation or backhaul requirement. The blue markers show a little improvement through interference subtraction, but also only require minimal backhaul. All red markers denote cases where the BSs exchange quantized receive signals (in frequency domain, with different numbers of quantization bits per real signal dimension), possibly using successive interference cancellation (SIC). The results show that in such a cell-edge scenario, BS cooperation offers the potential of increasing the average throughput by a factor of two, and reflects the throughput/backhaul trade-off predicted from information theory very well [19]. In asymmetrical interference scenarios, the performance of interference subtraction is strongly increased, while the overall cooperation gain is reduced [21].
Future measurements within the ARTIST4G project will focus on
- the frequency and suitability of scenarios in urban city for interference exploitation
- scheduling techniques in conjunction with interference exploitation [23],
- ad-hoc cooperation, where the exact cooperation scheme is decided after transmission started [24][25].

REFERENCES


[9] 3GPP TS 36.211 “Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation”, chapter 6.10.1


