A Testbed for Cooperative Multi Cell Algorithms

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ABSTRACT

In this paper, we describe the setup of a planned cellular testbed in downtown Dresden, Germany. It is developed by Technische Universität Dresden in cooperation with various other project partners within the German research project EASY-C. Aim of the testbed is the development and evaluation of innovative physical layer algorithms for next generation mobile communications systems. While the testbed is based on a baseline implementation of the 3GPP LTE physical layer, the focus of the research will be on techniques beyond LTE, such as multi-cell signal processing (often referred to as *network MIMO*) and cooperative or non-cooperative relaying. These schemes are known to be suitable for inter-cell interference cancelation and to thus strongly improve the spectral efficiency and fairness of cellular systems in theory, but have so far not been evaluated in practise. The testbed will furthermore allow the development and evaluation of improved simulation methodology for next generation mobile communication systems. The authors explain the testbed infrastructure, the hardware architecture and the algorithms of interest.

Categories and Subject Descriptors

A.0 [**General**]: Conference procedings

General Terms

Cellular Testbed Infrastructure

Keywords

cellular testbed, multi-cell signal processing, network MIMO, EASY-C.

1. INTRODUCTION

In September 2006, the 3GPP issued a study called *Evolved UTRA and UTRAN* [1]. The objective of this study was to define the long-term evolution (LTE) of the 3GPP access technology. In the second half of 2007, the specification of the LTE framework was scheduled for completion. These standardised algorithms are promising higher data rates and shorter latency, for example through the usage of classical MIMO concepts with an increased number of antennas at the base station and mobile side.

It is well known that the limiting factor in the spectral efficiency of cellular systems is the interference between adjacent cells. From an information theory point of view, it has been shown that cooperative multi-cell signal processing can be employed to exploit the signal propagation between cells and gain higher spectral efficiencies and diversity, rather than treating inter-cell interference as noise. Theoretical performance limits have for example been observed for uplink and downlink in [2] and [3], respectively, and concrete precoding algorithms have been investigated in e.g. [4]. Furthermore, cooperative or non-cooperative relaying can be used to improve spectral efficiency and coverage in certain cellular scenarios, as investigated in e.g. [5, 6]. However, the stated schemes have so far not found their way into standardization due to the lack of field trial data and analysis. It is for example known that practical issues, such as the synchronization of jointly processed terminals in time and frequency, and channel estimation for multi-cell MIMO pose major challenges that may possibly offset the theoretically predicted spectral efficiency gains through the innovative schemes. Furthermore, it has to be analyzed which effort in terms of additional network infrastructure or increased computational complexity has to be taken into account when implementing such network MIMO schemes.

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The objective of this project is to provide answers to these questions and thus enable to establish the roadmap of such innovative physical layer concepts towards the standardization of next generation mobile communications systems. In addition, we expect valuable field trial measurement data that can be used to improve or evaluate channel models and efficient system level simulation methodology.

Besides intensive research on the stated concepts, one major aspect of the EASY-C project (an abbreviation for **E**nablers of **A**mbient **S**ervices and S**y**stems Part **C** [7]) is a technology testbed for the evaluation of the observed multi-cell transmission and detection concepts in Dresden, Germany. In the following sections, we will give a short overview on the algorithms under investigation, and describe the planned testbed infrastructure based on cell sites of the German network operators T-Mobile GmbH and Vodafone D2 GmbH. We conlude this paper with a description of the used field trial hardware, which is provided by our project partner Signalion GmbH.

2. RELATED WORK

The performance of todays radio access networks is often dominated by the used link technologies such as diversity concepts, forward error correction, equalization, and point-to-point multi-antenna concepts. These concepts allow a quite accurate performance assessment by link simulations and system simulations using simple link models. It is expected that significant performance gains compared to these legacy systems can only be achieved by concepts that exploit the multi-dimensional cellular topology, and efficiently manage inter-cell interference. Examples for these new concepts are relaying, cooperative antenna techniques, interference management, simulcast / multi-cast bearers etc. in combination with advanced and cost efficient RF solutions. Evaluations based on today's simulation methodologies would require a much higher order of compute power and compute time over link-level simulations, and therefore appear infeasible. Hence, also little algorithm development has been carried out so far.

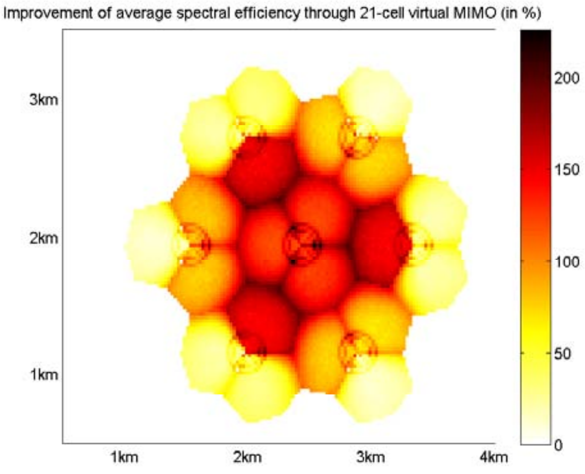

Figure 1: Improvement of average user capacity (in percent) for different locations, if LMMSE detection is applied within a virtual MIMO of 21 cells, compared to a conventional individual cell case [2].

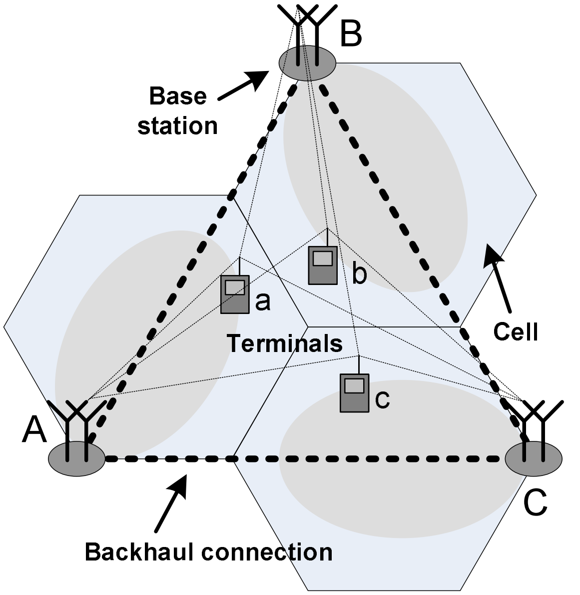

Figure 2: Schematics of multi cell cooperation using backhaul for data exchange between cooperating base stations

Analytical studies [2] have been carried out to evaluate the increase in spectral efficiency through system level simulations. This leads to the capacity improvements shown in Figure 1. In this simulation result, the average uplink capacity gains of a 21-cell network MIMO system compared to a conventional system (employing only receive diversity) are shown. The strongest gains of about 200% are experienced by the users at the cell borders, though a moderate gain is also observed in the inner parts of the cell. This corresponds to an observation in [8] that joint transmission and joint detection schemes are most effective if applied to users with similarly strong links to multiple base stations, as can be found at the borders between cells.

3. ALGORITHMS OF INTEREST

Within the project, innovative baseband signal processing algorithms for both uplink and downlink will be developed and evaluated. A typical cell setup for a distributed MIMO scheme is shown in Figure 2. Each of the terminals a,b or c has a dominant link to its serving cell A, B or C, respectively, but also moderately strong links to the other two base stations. We assume that the terminals use the same resources in frequency and time domain, such that they observe mutual interference that can be mitigated through multi-cell signal processing.

3.1 Uplink Multicell MIMO

The first algorithms under research employ joint detection in the uplink. This means that one or multiple mobile terminals (MT) are detected by multiple base stations. For these schemes, the impact of imperfect synchronisation in time and frequency domain, the impact of imperfect channel estimation and the joint power control are challenging topics that will be covered during the project. For these detection schemes, two basic algorithms were proposed. In the *Distributed Iterative Detection* (DID) scheme [9], every base station receiver performs a single user detection for its corresponding MT, while treating the other received signals as noise. Then, the neighboring base stations exchange the decoded data via the backhaul. With this information received at the neighboring cells, the interference can be reconstructed and pre-subtracted from the received signal before detection and decoding. In general, the base stations can exchange soft coded bits, hard detected bits or only subsets of reliable bits, as e.g. investigated in detail in [10]. This offers the degree of freedom to determine a reasonable tradeoff between spectral efficiency improvement and required backhaul.

Another cooperation strategy [11],[12] is the *Distributed Antenna System* (DAS) approach. In this case, the base station receivers are configured as access points (AP) which only perform RF front end processing. The quantized baseband signals are transmitted via the backhaul to a central unit (CU). Inside this CU, a joint detection and decoding of all received signals of the DAS is performed. This central unit can be located inside one of the base stations, e.g. in base station A in figure 2, or in a designated core network unit.

3.2 Downlink Multicell MIMO

A transmission strategy that will be investigated for the cellular downlink is known as joint transmission [13],[14]. Assuming fairly symmetric links between the base stations and the MTs in Figure 2, the base stations of different sites can transmit in a cooperative way to these mobiles, aiming at a coherent superposition of signals at the mobile terminals. Suitable precoding schemes, for example aiming at establishing fairness between involved terminals, have for example been investigated in [4]. In an FDD system, it is necessary that involved MTs feed back channel state information (CSI) to all jointly transmitting base stations. A special challenge in this context is the fact that all base stations involved into the same joint transmission will be subject to a different phase noise at the transmit antennas. Thus, the channel feedback has to be designed in such a way that it can provide an accurate knowledge on all involved channel coefficients as well as a high-rate feedback of the channel changes due to phase noise. Within the project EASY-C, different, possibly codebook-based feedback schemes will be implemented and evaluated w.r.t. system performance and delay.

4. TESTBED LAYOUT AND IMPLEMENTATION

The chosen testbed location in downtown Dresden covers various conditions, which are of special interest for evaluation of the cooperative algorithms:

- a representative area of a middle-sized European city
- hills in the south causing signal reflections
- a river through the city causing superrefractions / tropospheric refraction
- urban areas with multi-story buildings, leading to shadowing effects

The basic setup of the testbed platform consists of base stations and mobile equipment provided by the project partner Signalion GmbH [15]. The equipment will be denoted as *SORBAS devices* in the following. Other project partner's equipment, i.e. base stations, mobile and chip prototypes, will be inserted into the testbed for various test cases. The testbed PHY layer is mainly based on the 3GPP LTE standard [16]. For the joint channel estimation in the field trial, orthogonal resources for pilot symbols will be defined for each mobile and base station. With the focus on the physical layer only, simple MAC and network layer functionality will be implemented on the testbed equipment.

In the final stage, the testbed will comprise of 10 sites with a total of 25 cells. Additional interferers will be surrounding the outer cells in order to emulate the interference intensity and distribution of a network with three tiers of sites. The locations are real world GSM and UMTS sites which are operated by the project partners Vodafone D2 GmbH and T-Mobile GmbH. The averagel distance between the sites is about 800m. On these locations, new antennas, feeders and test base station hardware will be installed.

The base station hardware consists of the RF-hardware, including duplex filter and power amplifier, a GPS receiver, a control computer and a ethernet network switch (Figure 4). These components are assembled in a 19″ rack which is located inside the service room of the network operator. The control computer (CC) stores the data samples coming from the SORBAS device. Another task of the CC is the reconfiguration and remote control of the RF hardware. The GPS receiver is used for the time synchronisation of possi-

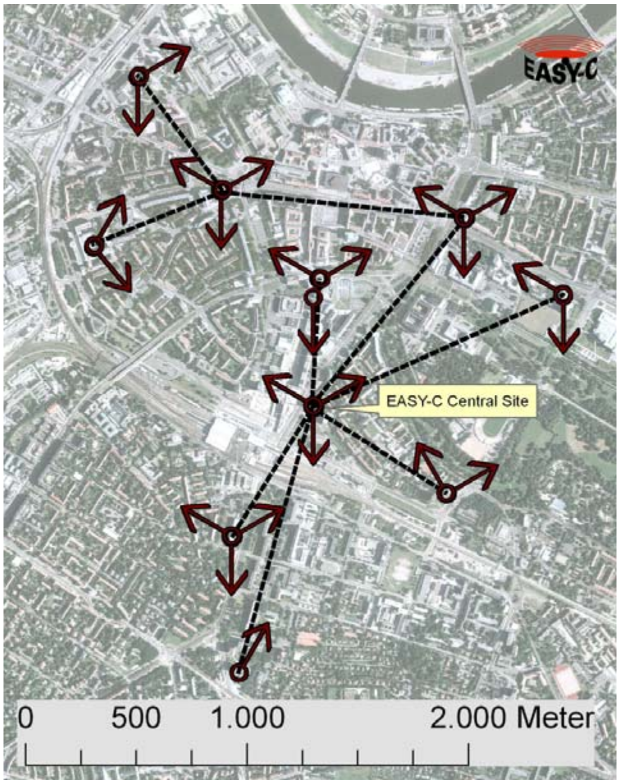

Figure 3: Testbed Layout in Downtown Dresden, Germany

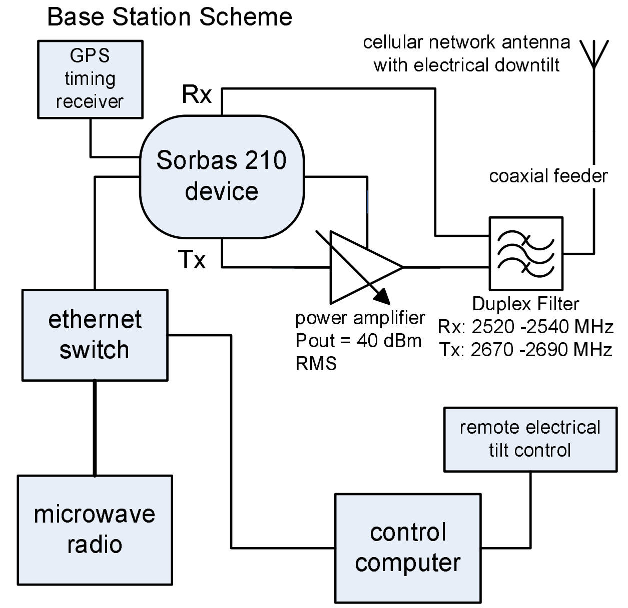

Figure 4: EASY-C Base Station Setup 1x1 configuration

bly cooperating base stations. The backhaul between the sites is realized through low latency microwave links. These links are operating in the 5 GHz frequency band and have a maximum throughput of 300 MBit/s.

The first lab trials are planned for January 2008. Thereafter, the Dresden testbed will be set up in three phases. In the first phase it will consist of one site with three cells that will be fully functional in 04/2008. This central site (labeled in Figure 3) is located near the Dresden main station with an antenna hight of 55 m above ground. The second phase will cover a one tier setup around the central site and consist of 6 sites with a total of 18 cells. It is planned to be launched in 10/2008. In a third phase, the testbed will be completed to the maximum configuration of 25 cells in 04/2009.

In Figure 3, the sites of the testbed are shown with an underlying aerial image of downtown Dresden. The arrows indicate the azimuth of the antennas installed at each site. The dotted lines refer to the microwave links between sites.

Coverage and overlapping simulations for this testbed layout have shown a sufficient outdoor coverage and a number of areas where the signals from multiple base stations strongly overlap. In these areas, the signals from different transmitters have an absolute difference of 5 dB and thus appear especially suitable for testing multi-cell cooperation. The coverage and overlapping statistics in Figure 5 show that more than 30% of the covered area are locations where we expect multi-cell cooperation to yield strong spectral efficiency improvements over a standard 3GPP LTE physical layer. The simulations were done with the ATOLL coverage planning tool with the following assumptions

- center frequency of 2.6 GHz
- control channel power of 33 dBm
- antenna pattern of a 65° 3dB beamwith base station antenna with 6 degree electrical tilt and 16 dBi gain

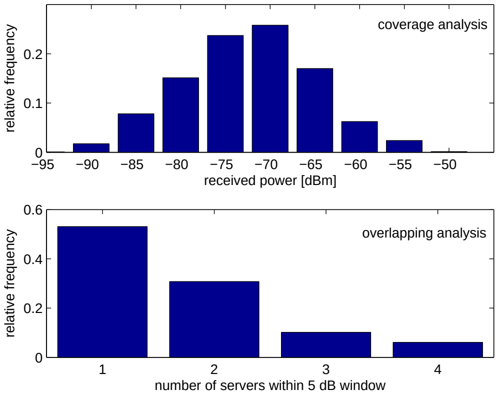

Figure 5: Coverage and overlapping statistics of the planned testbed. The covered area is about 7 km^2.

5. TESTHARDWARE ARCITECTURE

The EASY-C testbed will be operated in frequency division duplex (FDD) mode using the UMTS frequency extension band VII. Therefore, the following frequencies will be used:

- downlink 2670 - 2690 MHz
- uplink 2520 - 2540 MHz

The hardware platform, the SORBAS 210 device, will be used for the base station and UE side. A SORBAS device consists of four basic hardware modules. Figure 6 shows an example SORBAS device with one Tx and one Rx antenna. The enclosure is compatible to a standard 19″ rack, occupying a height of 6 units. The example configuration includes the following modules from left to right:

- STRxM: Signalion Tx/Rx Module, one Tx and one Rx branch are installed. The STRxM can accommodate up to four Tx or Rx sub-modules
- SRCM: Signalion Reference Clock Module, 10 MHz reference clock module
- SDRM: Signalion Digital Radio Module, one ADC and one DAC are installed
- SPWRM: Signalion Power Module.

The SDRM consists of a Digital Radio Card (SDRC), a Digital Radio Extension Clock, ADC and DAC and a DSP-based MAC/protocol card. The SDRC is an FPGA board for computationally complex baseband and digital frontend signal processing. It is characterized by the following main features: 4 x Xilinx Virtex 4 LX 160 FPGAs, 2 x 256 MByte SDRAM, 4 + 8 (optional 8 + 16) MByte SRAM, 4 x 512 Byte EEPROM, JTAG chain for the FPGAs and Various interfaces.

6. CONCLUSIONS

We presented an overview of the planned wireless communication testbed within the project EASY-C in downtown Dresden, Germany, and provided an overall description of the testbed layout and the planned work. The testbed

Figure 6: SORBAS-210 device in 1x1 configuration

structure allows the evaluation of cooperative multi-cell algorithms and cooperative or non-cooperative relaying as innovative physical layer concepts under realistic urban cellular network conditions. From an information theoretical point of view, these concepts promise significantly higher spectral efficiencies and system fairness, as they enable the cancellation or mitigation of inter-cell interference. Aim of the EASY-C project is to show how much of this gain can be achieved under realistic conditions such as limited backhaul and latency, while also taking into consideration additional physical layer overhead that is required for network MIMO channel estimation, synchronization in time and frequency etc. The project will also provide the involved partners with comprehensive field trial measurement data that can be used for the evaluation and derivation of channel models and next generation cellular network simulation methodology.

7. ACKNOWLEDGMENTS

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