1: Interference management for indoor broadband system  
Supervisor: Troels B. Sørensen (tbs@es.aau.dk)

Motivation

High speed data transmission is foreseen to count for the main volume of mobile traffic consumption in the future wireless networks. Moreover, 80% of the data traffic is expected to be generated inside of buildings, i.e., an office building, airport or on campus. Along with the fast evolution of data traffic need (traffic volume and peak data rates), it will become extremely difficult to serve such ‘hotspot’ areas from existing macro networks. For this reason, the deployment of small base stations (BS), e.g. Femto BS, is very much discussed in connection with next generation mobile communication (4G). Femto BSs could be used to provide capacity (and coverage) in local area hot-spots and thus complement existing macro/micro networks.

One of the problems of cellular systems, and in particular for the indoor system is that operators typically have to operate such an indoor system on one carrier due to spectrum scarcity. A key issue is therefore to handle the interference between the BSs. The straightforward approach is to somehow divide the spectrum resource (the carrier) for spatial reuse over the building; from previous studies it is quite well established that the best reuse pattern for typical indoor environments is close to reuse 1/2. Therefore, if we want to further increase capacity and peak data rates we need more advanced techniques to deal with the interference. In this project, the idea is to explore the potential of using uplink interference cancellation in such scenarios. Particularly for an indoor system this is feasible, given the possibilities to have the small base stations cooperate.

Content

1. Based on a site-specific framework (including models for building geometry, propagation, and user distribution) investigate the path loss distributions, link budgets, and multi-user interference situation
2. Investigate the uplink performance of a reuse two system based on a simplification of a reference system (the UTRAN LTE) and with (realistic) small scale fading added on top of the path loss model
3. Investigate the use of interference cancellation (IC), and geometrical alignment of interference by scheduling, to increase the capacity over the fixed reuse system
4. Investigate the system performance as a function of number of active users, density of BSs, user QoS, etc.
5. Clarify the implications and assumptions in relation to the reference system for the required operation of the system
6. Potentially include the use of several (frequency selective) carriers in the analysis.

A system evaluation framework needs to be defined with appropriate system performance metrics and variables of interest for the studied problem. Specifically, this entails to make appropriate simplifications in the implementation of the systems.
The study should start by reviewing literature on interference cancellation, indoor propagation and performance related to indoor broadband systems.

Prerequisites
Good understanding of mobile communication, radio access concepts and propagation is needed, as well as experience with MATLAB programming.

References

Modelling the indoor broadband channel  
Supervisor: Troels B. Sørensen (tbs@es.aau.dk), Zhen Liu (zl@es.aau.dk)

Motivation

Ray-tracing as a tool to predict radio wave propagation has been known for many years. Academic literature is full of research work related to ray-tracing and books have been written on the topic. Based on ray-optical principles, ray-tracing can be used to predict the path loss and multipath propagation between a transmitter and a receiver. Recent development in fast and efficient computing hardware and easy access to three-dimensional digital terrain and building data has spurred a renewed interest in the application of ray-tracing. It is even being used by some operators for the planning of their cellular networks.

In this project a commercial ray-tracing tool is to be used to investigate the applicability of ray-tracing to indoor environments, possibly including the indoor-to-outdoor propagation. The primary goal is to evaluate what characteristics can be derived from ray-tracing predictions and see how well it aligns with reality (a simple comparison to measured path loss data will be possible to verify the overall accuracy of the method). A secondary goal is to investigate the deployment of small indoor base stations (BS), e.g. Femto BS, considering the trade-off between coverage and isolation between them, thus potentially leading to recommendations for indoor service provisioning.

The interest in indoor arises from the general assumption that 80% of high speed data transmission is expected to be generated inside of buildings. Next generation mobile communications therefore consider the deployment of Femto BS inside of buildings to meet the need for high data rates and capacity in the wireless network.

Content

The foreseen content of the project will include:

1. Construction of a building model (or part of building)
2. Investigations using ray-tracing tool
3. Analysis of the sensitivity to constituent parameters and geometric modelling
4. Comparison to empirical data
5. Characterization of channel dynamics from predictions (statistical description of spatial and temporal dispersion)
6. Investigation of access point deployment as to coverage and isolation

A specific building will be assumed for which measured path loss data are available (plus potentially some multipath measurements). The study should start by reviewing literature on ray-tracing and the propagation modelling applied in the predictions.

The available tool contains a 3D modelling tool for indoor environments and antennas, in addition to the ray-tracing prediction tool.

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Prerequisites

Good understanding of radio wave propagation and characterisation.

References

It is suggested to check the open literature on ray-tracing, as well as the literature used in connection with the course on “Propagation, antennas and diversity” on the 8th semester (MobCom specialisation). A manual for the tool can be made available.
Background:
Today's RFID is primarily utilized as a tool for identification in supply chain management services. But RFID has the potential of becoming ubiquitous, and it is therefore considered a key technology for pervasive networks and services [1]. Such widespread use of RFID systems to provide accurate identification of all tagged objects, requires a dense deployment of RFID readers, introducing collisions as the readers interfere with each other.

When considering reader collisions they cover two different collisions: 1) Reader-tag collision, where a tag is located within the read range of multiple readers. The reader signals interfere with each other, making it challenging for the tag to decode as much as just a single reader request, not impossible though. 2) Reader-reader collision, where a reader signal interferes with the reception of a tag response at an adjacent reader. This can occur when readers are sufficiently spaced so their interrogation zones do not overlap, but their interference range reach into interrogation zones of adjacent readers. The EPC Global C1 Gen 2 standard [2] implements a dense-reader-mode, allowing densely deployed readers to operate simultaneously in separate frequency bands. Modern readers then implement filters that can separate frequency bands and hereby filter out the main part of the interference. However, tags do not have this option, and are thus forced to cope with the interfered signal.

Immense work have been published in the area of reader collision already, proposing different methods to utilize the dense-reader-mode and optimize for low probability of reader collision. In [3, 4] the problem of reader collision is thoroughly described and existing methods to cope with this problem are surveyed. Recently [5, 6] presents schemes to dynamically adapt modulation depth and transmission power, respectively, to avoid reader collisions.

Project Idea:
Normally interference is considered a limitation, an imperfection that you had to cope with in one way or the other. What if interference could be utilized constructively? In this project we will investigate the impact of interference, in the context of RFID systems, and whether the interference can be utilized constructively. This project focusses on two different applications:

1. Blocking a tag response, i.e. preventing tags from sending replies. This can be used to block tags for security purposes, or mitigate the problem of false positive detection of tags.
2. Foster cooperative reading of tags. While interference is harmful for reception, it can be seen as an additional RF power available to be harvested by the tag and thus help the tag to get its response through. This means that the interference from an adjacent reader helps energizing the tags to be interrogated, so they can respond with high probability, i.e. the range of the interrogating reader is effectively increased due to the interference.

The results obtained in this project should be based on both analytical and experimental investigations using commercial passive UHF tags and readers. The setup for the experimental evaluation is already available in the RF lab.

References:
4: SMALL ANTENNAS ON DIELECTRIC MATERIALS FOR 4G APPLICATIONS

Following the 3rd generation UMTS, LTE is the 4th generation solution promising higher transmission and reception data throughput with MIMO.

Antennas have become of a particular interest since radio performances depend mainly on the antenna system. Today’s antennas need to cover a broader bandwidth, be more efficient and fit into smaller and thinner handsets eventhough these requirements are contradictory [1].

Shrinking antenna size is one of the prerequisite for MIMO systems that is going to implement more than one antenna in the mobile phone to achieve 4G throughput.

This project is focusing on the challenge to design small PIFAs fitting in the limited space of the palm size terminals, using ceramic material. A minimal bandwidth of 20 MHz and a minimal matching of -6 dB have to be ensured.

Also, the main drawback of current ceramic antennas is their susceptibility to significantly altered performances when other components are placed in close proximity.

Further human hand influence can be investigated on this newly designed antennas.

The outcome of the project is:

- A state of the art on ceramic antennas and ceramic material
- A full description on ceramic antennas behavior for one design resonating at one frequency
- To achieve significant size reduction
- A description of the change of the main antenna parameters while changing the resonance frequency and keeping the same material
- To overcome their susceptibility
- To determine the human body contribution
- To try to fit two ceramic antennas into the same handset

Supervisors:

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Group:

1 or 2 students

References:


Recommended literature:

Balanis – Chapter 2
Sanchez-Hernandes, Multiband integrated antennas for 4G terminals – Chapter 1
I. BACKGROUND

The throughput achieved by wireless communications is limited by interference. Interference alignment is an emerging technology that has the potential to enable end-users to meet the throughput requirement of future flexible networks [1]–[4].

When a receiver possesses multiple antennas, a multi-dimensional space can be created for communication. For example, a receiver with 2 antennas can create a 2 dimensional space, meaning that it can decode up to 2 different signals. Each signal occupies a 1 dimensional subspace. One signal can be the signal intended to the user and the other signal is an interferer. When more than 1 signal interferes, the receiver becomes overloaded and performance degrades. However, transmission can be arranged so that all the interferers are aligned in the sense that they belong to the same one dimensional subspace. Hence the remaining one dimensional subspace is interference free and can be used to carry the signal of interest although more than one interfering signal is present.

Fig. 1. Interference Alignment and Cancellation example.

Recently, interference cancellation has been proposed to combine with interference alignment to improve the performance in scenarios where neither interference alignment nor cancellation applies alone [5], [6]. Fig. 1 is an example to show the advantage of the interference alignment and cancellation (IAC) scheme in the uplink transmission. The first user equipment (UE) wants to transmit two packets while the second UE wants to transmit one packet. In the traditional transmission scheme, each of the Base Stations (BSs) gets two linear equations with three unknown packets and hence decoding performance can be very low.

With IAC, the two UEs encode their packets in a special way to align the second and third packets at BS1 but not at BS2, as shown in the figure. Then, BS1 can treat the second and third packets as one unknown and decode the first packet. BS1 then sends the decoded packet to BS2, which can perform interference cancellation to subtract the effect of the known packet. As a result, BS2 can decode the second and third packet. Thus, the throughput of the system is not bounded by the number of antennas per BS. This scheme can be compared to a full cooperation scheme between BSs where BS1 sends its 2 received signal to BS2. BS2...
gets 4 equations to solve for 3 unknowns. However, this situation requires twice as much information transfer compared to the IAC scheme.

Moreover, introducing relay nodes to the system can assist the transmission. The relay-aided interference alignment schemes were studied in previous literatures [7]. In the relay-aided system, the transmission can be divided into two-phases. The relay stores the received signal during the first phase and then transforms and sends the new signal during the second phase. The relay can be very helpful by reducing the size of the signalling space over which interference alignment can be accomplished. Therefore, it will be very interesting to see the benefits of the relay in the system where IAC applies.

II. OBJECTIVES

To apply IAC in the relay-aided system and analyze the performance.

III. CONTENTS

The main topics which shall be addressed in this project are:

- Propose IAC scheme in the relay-aided system.
- Derive the degrees of freedom of the system.
- Performance analysis of the proposed IAC-based scheme.
- Performance comparison between existing interference management and the proposed IAC-based transmission schemes in the relay-aided system.

IV. PREREQUISITES

- Basics of wireless communication.
- Linear algebra and matrix theory.
- Optimization theory.

V. EXPECTED ACQUISITIONS

- Deep understanding towards interference management in cellular networks particularly interference alignment.
- Optimization skills and solid knowledge about signal space.

REFERENCES

6: Near-field probe calibration and compensation

Supervisor: Prof. Gert Frølund Pedersen, APNet, A6-206 (gfp@es.aau.dk)
Industrial PhD-student Morten Sørensen, Bang & Olufsen / APNet, A6-206 (mos@es.aau.dk)

Introduction

All electrical apparatus cause radiated emission which can disturb radio communication and other electrical apparatus. In order to obtain electromagnetic compatibility (EMC) the legal authorities have set up some mandatory requirements regarding radiated emission among other things. These requirements have always been claimed on the whole apparatus, but not to the individual modules that are part of the apparatus. The total radiated emission depends on many factors, including emissions from PCB’s, common mode currents on cables, the modules relative positions, shielding, product chassis, etc. The whole thing is further complicated by the fact that the foregoing factors are not independent. The leading literature [1, 2] describes many qualitative methods which for each noise source makes it possible to suppress electromagnetic radiation and interference, but there is not currently accurate quantitative methods to predict the effect on the apparatus level of an effort made at module level or made to the architecture. These quantitative methods are the objective of the innovation consortium “EMC Design – First Time Right” conducted jointly by AAU, Bang & Olufsen and other private companies.

The objective for this consortium is to develop a method where you can simulate an apparatus total radiated emissions based on among other things the near-field characteristic of the modules, where coupling between modules and cables as well as influences from the chassis and the rest of the immediate surroundings are included.

This final thesis will focus on two main areas: Electromagnetic theory and numerical methods together with near field scans of modules. The project will consist of both experimental and theoretical work.

Expected content

Near-field scan is a relatively new discipline within EMC, and there is a task of improving existing measurement methods. The objective of near field scanning is to infer the electric and/or magnetic fields surrounding IC chips, PCBs, etc. In the measurement part of the process, a probe is scanned over a surface above or surrounding a device under test and the output of the probe is recorded. This output may be a scalar quantity or a vector quantity. In the data analysis part of the procedure the objective is to process the output of the probe to recover the electric and magnetic fields. This is illustrated in figure 2 below here.
A separate problem is that the probe enters the reactive near field of the PCB, why measurement disturbs the object being measured. The extent of the disturbance must be investigated and it must be investigated whether it is possible to compensate for disturbance.

The final thesis can work within the following areas:

- Calibration (determining the response characteristics of the near field probe)
  - An experimental approach
  - A simulation approach
- Compensation (trying to remove or minimize the effects of the near field probe on the field components being measured)

**Prerequisites**

Courses in el.-magn. theory and numerical methods.

**Literature**


Can you fix the iPhone? Developing a method to predict the influence of the human body on the antenna system.

Supervisors: Dr. Mauro Pelosi mp@es.aau.dk and Prof. Gert. F. Pedersen gfp@es.aau.dk

After the iPhone 4 problems, it is now clear also to the general public that the human body influence can drastically decrease the antenna performance [1]. The human tissues are lossy, and dissipate the electromagnetic energy by heat, so that there is less power available for radiation. This in turn causes a reduced battery life and throughput, with the possibility of dropping phone calls. We knew that for some time, but there is always room for improvements [2]!

This project proposes to investigate the robustness of the antenna design for small terminals with respect to the perturbations (losses caused by the human hand/head). It is fundamental to predict in the first design stage the final behavior of the antenna system.

This can be investigated using our supercomputer Fyrkat, our in-house Finite Difference Time Domain (FDTD) code and measurements.

• What is the difference between the antenna performance in free space and when in contact with the human body?
• What is the role of the antenna near fields?
• Can we find more general design guidelines?

The candidates are required to have the following skills:
• Matlab knowledge
• Basic electromagnetics and antenna knowledge

8: Inter-cell Interference and LTE Systems:
Impact on the Performance and Testing Recommendations

Supervisors:
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Support from the local research office of Agilent technologies in Aalborg

Background
In wireless cellular systems, cell edge performance is a major driver of end user experience. A cell edge positioning combines a greater propagation distance from the base station and greater proximity to sources of inter cell interference. These two aspects generally translate into low data rates for users occupying such a position and calls for special attention as marginal conditions are critical to overall network performance.

Receiver performance requirements for UMTS (3G) were defined relative to known levels of Gaussian noise. In the case of W-CDMA (Wideband – Code Division Multiple Access), all transmissions occupy the entire channel bandwidth and a Gaussian noise accurately models the effect of inter-cell co-channel interference. The aggregation of such interference signals creates a uniform Gaussian interferer even when the individual transmissions may be intermittently present due to packet scheduling. The use of different spreading codes rather than transmission power as the primary method of altering data rates further adds to the uniform nature of the interference.

In OFDMA systems (LTE), the primary method for altering data rates is partial allocation of the RB (Resource block) in the channel. This coupled with the TDMA (Time Division Multiple Access) nature of allocations creates a much less uniform interference signal. Depending on the traffic mix and use of frequency-selective scheduling, the resulting interference signal could vary widely in both frequency and time as compared to the interference generated by CDMA systems. Furthermore, more advanced interference cancellation receivers require a more realistic signal comprised of partially or fully coded interference signals to enable the receiver to use interference cancellation algorithms that can differentiate between wanted and unwanted signals.

In LTE the initial receiver performance requirements were developed using the simplified AWGN model although this has been recently augmented with use of a partially allocated interferer with additional fading applied. However, in any operational network the nature of the cell edge interference in the downlink, and the uplink interference at the eNB, will be far from Gaussian or partial static allocation. Initial simulations for the uplink case suggest that AWGN is an accurate predictor of performance for users near the cell centre but for cell edge users, AWGN may overestimate throughput by 50% compared to a more realistic interferer [1][2].
**Project description**
This project proposal focuses on inter-cell interference impact on LTE (4G) systems with special focus on the cell edge. The objective is to properly model and evaluate the inter-cell interference and especially its impact on the performance of the cell edge users. The project will be organized in the following four phases:
1. Get fair understanding of LTE UE (User equipment) and network aspects.
2. Setup an LTE simulation environment.
3. Assess the impact of white/colored interference on system performance.
4. From that assessment, derive link-level requirements.

This master project is within a framework of industrial collaboration with Agilent Technologies, a leading company in designing and supplying test and measurement equipment for radio communications. If successful, the project could lead to a 3GPP contribution. As a supporting tool in carrying out the project, a System Vue license would be granted to the student for the time of the project. More information about System Vue can be found here: [http://www.home.agilent.com/agilent/product.jspx?nid=-34264.0.00&lc=ger&cc=DE](http://www.home.agilent.com/agilent/product.jspx?nid=-34264.0.00&lc=ger&cc=DE)

**Requirements**
The students should have knowledge about wireless cellular systems, OFDMA systems, receiver algorithms, basic knowledge of statistical modelling. Programming skills and experience with scientific programming environment/problems (e.g. MATLAB) is essential.

**References**
9: Optimization in design of precoder and decoder for coordinated AP systems using MMSE criterion

Supervisors: Maryam Rahimi (mar@es.aau.dk), room A6-205 APNet
Elisabeth de Carvalho (edc@es.aau.dk), room A6-212 APNet

Background:
In conventional wireless communication systems, any user is connected to a single access point (AP) via a wireless link. The AP is the point through which the communication accesses the wired network. One AP serves a geographical area called a cell. Several APs are placed appropriately close to ensure proper coverage of a larger geographical area. Each AP operates independently from the other APs. Thus, the signal sent from an AP to a user inside its cell might also be received by a user in a neighboring cell, as an unwanted signal. This gives rise to the main limiting factor in today’s wireless communications: inter-cell interference. For the user, the effects of interference are usually catastrophic: interference reduces dramatically the data rate or makes the communication fail [1].

Coordinated Access Points (CAP) is a new architecture where the APs are connected to each other and coordinate their operation. More specifically, the APs are connected to a central control unit through a high speed wired connection. The control unit coordinates the operations among APs and centralizes all the computations necessary for the communications. Because the APs are coordinated, inter-cell interference is reduced: communication failures are avoided and data rates to users dramatically increase (roughly speaking if two APs coordinate, the user could expect doubling of its peak data rate) [2, 3].

In this project, we will consider the case of multiple coordinated APs communicating with multiple users. We will explore several aspects of the transmitter and receiver architecture. In particular, it is possible to form beams at each AP that direct the power towards a given direction. Those beams have to be jointly coordinated at the APs and matching beams have to be designed at the user equipment. As shown in figure 1 for transmitting signals $s_1$ to user $U_1$ and signal $s_2$ to user $U_2$ we have both signals available at both APs. First, $s_1$ and then $s_2$ is transmitted from AP1&AP2. It can be seen Power sent from AP1&AP2 adds up at the user.

![Figure 1: serving users with CAP system](image)

Those beams have to be efficiently design to maximize the data rate or fulfill the quality of service at the users. In principle, the design should involve a joint optimization of the transmitter and the receiver. Such a design is often computationally complex. This project aims at finding and testing methods that lead to designs with lower computational requirements. Those designs are based on the following features:
- The beamforming design is based on the Minimum Mean Squared Error (MMSE) criterion: this is a well known criterion that has the potential to lead to simple closed form solution [4].
- Iterative algorithms relying on alternating optimization: beamforming at the transmitter is first optimized while the receiver architecture is fixed and second, the receiver architecture is optimized while the transmitter structure is fixed [5].

Working on this project leads students to get a general view of how coordinated access points in cellular systems work and how they are different from a system without coordination. They would gain a good understanding of MMSE criterion in beamforming designs. Moreover they can deal with some mathematical aspects of the project which is optimization problem in transceivers and learning different methods or algorithms as a solution of the problem.

**Objectives:**
Find efficient transmission and reception architectures for coordinated AP systems using the MMSE criterion.

**Content:**

The main topics which shall be addressed in this project are:
- Formulating the MMSE criterion to find the beamforming structures for coordinated APs.
- Applying alternating optimization approaches
- Simulate and assess performance using MATLAB programming.

**Prerequisite courses:**

1. Basics of mobile communication
2. Linear algebra and matrices
3. Probability and statistical signal processing

**Bibliography:**


