Abstract: This deliverable includes contribution of the partners that works specifically in the D3.2 task and the contributions from each partner is organized in chapters. After a brief introduction in the chapter 1, in the chapter 2 is proposed to use the given location of the nodes in the cooperative ad-hoc networks, in order to allow the distant MSs exploit MS-MS links to communicate with the APs via multi-hop connections. In chapter 3 MTMR is exploited both in macro diversity and Alamouti diversity, which resulted in significant gains in terms of transmission power. In the chapter 4 a Dynamic Resource Allocation architecture is presented for the WiMAX and a channel estimation method based on the positioning information is exploited to minimize retransmission and consequently improve overall throughput. Chapter 5 utilize localization information to determine the spatial spectrum hole for frequency reuse in the cognitive radio concept.


Disclaimer:
Executive Summary

This document includes contributions related to intermediate version of a location based cross-layer optimisation for PHY/MAC and the contributions are related to each technology and is organized in chapters.

In chapter 2 there is a description of the intended work related to cross-layer optimization of PHY/MAC parameters take a starting point in existing work published, in which a model-based optimization of transmission power and PHY mode (bit rate) is considered for a message broadcasting application in vehicular networks. An extension of the published approach will be taken for WHERE scenarios, where adaptation of PHY/MAC parameters for global/fair optimization of performance and reliability for whole groups of nodes will be considered. It is expected that the proposed PHY/MAC optimizations are considered jointly with strategies for using multi-hop relays, which is investigated in tasks 3.3 and 3.4. Example scenarios are provided for both single hop and multi hop cases. In chapter 3 we explore the multiple transmit / multiple receive (MTMR), starting from the concept of coordinated multi-point transmission/reception (CoMP) envisioned in LTE-Advanced. Radio Resource Management (RRM) over the sub-carrier resource is used based on the fact that underlying OFDMA transmission technique exclusively assigns the sub-carrier resources to one user. Both Cyclic Delay Diversity (CDD)\([\text{DK01}\]) resulting in cellular CDD (C-CDD) and space time block coding (i.e., Alamouti coding \([\text{Ala98}\]) resulting in the cellular Alamouti technique (CAT) are applied. In chapter 4 we propose to evaluate the performance of the WiMAX system where the DRA will use the channel estimated based on positioning information. The proposed system will be evaluated using the Proportional Fair Scheduling (PFS) policy and the channel on the instant of the transmission for link adaptation, is estimated based on the evolution of both channel and positioning information. Least Mean Square (LMS) can be the method for tracking of the evolutions. In chapter 5 we base our study in cognitive radio, analysing the interference-awareness cognitive radio (IACR) paradigm, where the cognitive users utilize channel side information to evaluate the interference potentially caused by the cognitive transmitter to primary receivers. Communication between cognitive users occurs only if the interference power is below an acceptable threshold. This case is defined as the spatial spectrum hole that offers the opportunity for frequency reuse. We seek to address the problem in two folds: (1) evaluate the channel capacity of the of IACR in the Gaussian channel and the optimum power setup in the secondary transmitter, and (2) channel estimation between the secondary transmitter and the primary receiver interferes with the primary communication, using localization information to determine the spatial spectrum hole for frequency reuse. Chapter 6 concludes this document highlighting main work envisaged and the achievements.

Main conclusion are that for cooperative ad-hoc networks, the optimization goal will in the advanced studies will be to determine the most suitable transmission power and PHY mode, given the location of the nodes and possibly other parameters, since not all mobile stations are within coverage of the application points. Instead, the distant MSSs exploit MS-MS links to communicate with the APs via multi-hop connections. In this case another dimension is added to the optimization problem, since it is possible to exploit cooperation between ad-hoc nodes.

MTMR study which exploits diversity both in macro diversity, the cell Cyclic Delay Diversity (C-CDD) is applied and Multiple transmission as cellular Alamouti diversity (CAD), showed that transition power saving is achieved. The throughput performance with halved transmit power is better than the performance of the reference system. Results shown that for the adaptive transmit power scheme depending on the user’s position (the adaptive C-CDD) the received diversity and the resulting performance gain are increased in a wider area around the cell border. In contrast to the non-adaptive C-CDD with halved transmit powers at both BSs, the power adaptation guarantees the reception of the signal with maximum power throughout the whole cell.

A DRA for WiMAX system is described with all the details related to the Radio Resource Management. Is also demonstrated how the delay between the scheduling and transmission can affect the throughput, and a fast fading channel estimation method based of positioning is proposed. Although the whole methodology for this evaluation was described, the results concerning the system performance will be presented in the advanced version of cross-layer optimization.

The capacity theorems for the IACR system in two scenarios. One scenario was about the situation, where the secondary transmitter had the perfect channel side information. The other was about the situation, where the secondary transmitter did not know the channel between the primary receiver and itself, but obtained the channel variance from localization systems. Numerical results have shown that the localization information could help the IACR system, but could not offer comparable performance with the case with perfect channel side information.
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<thead>
<tr>
<th>Partner</th>
<th>Name</th>
<th>Phone / Fax / e-mail</th>
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</thead>
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<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>AI</td>
<td>Air Interface</td>
</tr>
<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>ARQ</td>
<td>Automatic Repeat Request</td>
</tr>
<tr>
<td>AoA</td>
<td>Angle of Arrival</td>
</tr>
<tr>
<td>BS</td>
<td>Base Station</td>
</tr>
<tr>
<td>CAT</td>
<td>Cellular Alamouti Technique</td>
</tr>
<tr>
<td>C-CDD</td>
<td>Cellular Cyclic Delay Diversity</td>
</tr>
<tr>
<td>CIR</td>
<td>Channel Impulse Response</td>
</tr>
<tr>
<td>CRRM</td>
<td>Common Radio Resource Management</td>
</tr>
<tr>
<td>FER</td>
<td>Frame Error Rate</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSPS</td>
<td>Giga-Samples Per Second</td>
</tr>
<tr>
<td>HO</td>
<td>Hand Over</td>
</tr>
<tr>
<td>LB</td>
<td>Location Based</td>
</tr>
<tr>
<td>LDD</td>
<td>Location Dependant Data</td>
</tr>
<tr>
<td>LOS</td>
<td>Line Of Sight</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MBSFN</td>
<td>Multicast Broadcast Single Frequency Network</td>
</tr>
<tr>
<td>MS</td>
<td>Mobile Station</td>
</tr>
<tr>
<td>MTMR</td>
<td>Multiple Transmit / Multiple Receive</td>
</tr>
<tr>
<td>MT</td>
<td>Mobile Terminal</td>
</tr>
<tr>
<td>NLOS</td>
<td>Non Line Of Sight</td>
</tr>
<tr>
<td>NRTV</td>
<td>Near Real Time Video</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Services</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio Access Network</td>
</tr>
<tr>
<td>RAT</td>
<td>Radio Access Technique</td>
</tr>
<tr>
<td>RNC</td>
<td>Radio Network Control device</td>
</tr>
<tr>
<td>RRM</td>
<td>Radio Resource Management</td>
</tr>
<tr>
<td>RRSI</td>
<td>Received Signal Strength Indicator</td>
</tr>
<tr>
<td>RSS</td>
<td>Received Signal Strength</td>
</tr>
<tr>
<td>RT</td>
<td>Ray Tracing</td>
</tr>
<tr>
<td>SCM</td>
<td>Spatial Channel Model</td>
</tr>
<tr>
<td>SDMA</td>
<td>Spatial Division Multiple Access</td>
</tr>
<tr>
<td>TAS</td>
<td>Transmit Antenna Selection</td>
</tr>
<tr>
<td>ToA</td>
<td>Time of Arrival</td>
</tr>
<tr>
<td>TFF</td>
<td>Time To First Fix</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UTRA</td>
<td>Universal Terrestrial Radio Access</td>
</tr>
<tr>
<td>WPS</td>
<td>Wi-Fi Positioning System</td>
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1 Introduction

WP3 is mainly to investigate advanced protocol-algorithms for OFDM based radio access networks exploiting positioning information, where the key activities focus on enhancements to adaptive synchronisation, channel estimation and MTMR techniques; crosslayer optimisation for PHY/MAC; cooperative communication techniques for coverage capacity enhancement; and session roaming. Three deliverables are dedicated to intermediate stage of the WP: D3.1 for Intermediate Location based optimisation for PHY algorithms/protocols, D3.2 Intermediate Relaying and cooperative communications enhancements based on positioning data and this D3.3, which consists on Intermediate Location based cross-layer optimisation for PHY/MAC.

This deliverable includes contribution of the partners that works specifically in the D3.2 task and the contributions from each partner is organized in chapters.

In chapter 2 there is a description of the intended work related to cross-layer optimization of PHY/MAC parameters take a starting point in existing work published in [WCNC09 paper], in which a model-based optimization of transmission power and PHY mode (bit rate) is considered for a message broadcasting application in vehicular networks. An extension of the published approach will be taken for WHERE scenarios, where adaptation of PHY/MAC parameters for global/fair optimization of performance and reliability for whole groups of nodes will be considered. We expect that the proposed PHY/MAC optimizations are considered jointly with strategies for using multi-hop relays, which is investigated in tasks 3.3 and 3.4. Example scenarios are provided for both single hop and multi hop cases. In chapter 3 we explore the multiple transmit / multiple receive (MTMR), starting from the concept of coordinated multi-point transmission/reception (CoMP) envisioned in LTE-Advanced. Radio Resource Management (RRM) over the sub-carrier resource is used based on the fact that underlying OFDMA transmission technique exclusively assigns the sub-carrier resources to one user. Both Cyclic delay diversity (CDD [DK01]) resulting in cellular CDD (C-CDD) and space time block coding (i.e., Alamouti coding [Ala98]) resulting in the cellular Alamouti technique (CAT) are applied. In chapter 4 we propose to evaluate the performance of the WiMAX system where the DRA will use the channel estimated based on positioning information. The proposed system will be evaluated using the Proportional Fair Scheduling (PFS) policy and the channel on the instant of the transmission for link adaptation, is estimated based on the evolution of both channel and positioning information. Least Mean Square (LMS) can be the method for tracking of the evolutions. In chapter 5 we base our study in cognitive radio, analysing the interference-awareness cognitive radio (IACR) paradigm, where the cognitive users utilize channel side information to evaluate the interference potentially caused by the cognitive transmitter to primary receivers. Communication between cognitive users occurs only if the interference power is below an acceptable threshold. This case is defined as the spatial spectrum hole that offers the opportunity for frequency reuse. UniS seeks to address the problem in two folds: (1) evaluate the channel capacity of the of IACR in the Gaussian channel and the optimum power setup in the secondary transmitter, and (2) channel estimation between the secondary transmitter and the primary receiver interferes with the primary communication, using localization information to determine the spatial spectrum hole for frequency reuse. Chapter 6 concludes this document highlighting main work envisaged and the achievements.

2 Localization based performance and reliability optimization

2.1 Work intentions

This chapter describes the intended work related to cross-layer optimization of PHY/MAC parameters, which is intended to work in relation to other WP3 activities. The plans for this work is to take a starting point in existing work published in [NGR+09], in which a model-based optimization of transmission power and PHY mode (bit rate) is considered for a message broadcasting application in vehicular networks. Figure 2.1 depicts the general view on cross-layer optimization that has been adopted in this work.
An extension of this approach will be taken for WHERE scenarios, where adaptation of PHY/MAC parameters for optimization of performance and reliability will be considered. Specifically in this work, we will assume known positions of individual nodes instead of the average density on the surrounding area. A major difference from the previous work is that we do not consider the message delivery probability of a specific unacknowledged broadcasting application, but we will assume that frame transmissions are guaranteed and therefore we will consider a more general link/route quality metric, e.g. in terms of BER or achievable throughput rate.

The adjustment parameters that we consider are transmission power and the use of multi-hop transmissions. This means that the proposed PHY/MAC optimizations are considered jointly with strategies for using multi-hop relays, which is investigated in tasks 3.3 and 3.4. This work is scheduled to be performed in Year 2 of WHERE.

In the following, an example scenario that could be targeted within this work is presented.

### 2.2 Example scenario

Figure 2-2: All MS covered in single hop. Figure 2-3 presents 2 different cases. In these figures the inner region around the AP (dark) covers the MS where a high bit-rate is achievable, whereas the outer region (light) shows which nodes can only achieve a low bit-rate when communicating with the AP.
In Figure 2-2 a high transmission power is used in order for all MSs to communicate directly with each AP, however not all at the maximum bit-rate, since a too high transmission power would cause major interference. In Figure 2-3 not all MSs are within coverage of the APs. Instead the distant MSs exploit MS-MS links to communicate with the APs via multi-hop connections. In this type of scenario, the optimization goal would be to jointly determine the most suitable transmission power and whether to use relaying nodes/multi hop transmissions to reach distant nodes. A secondary objective for this work is to consider mobile scenarios and investigate how mobility information/prediction can be exploited to enhance performance and reliability.

3 Link Level Interface modelling for OFDM

3.1 Advanced LLI for MTMR

The concept of coordinated multi-point transmission/reception (CoMP) is envisioned in LTE-Advanced which implies a coordination of the transmission from multiple transmission points in the downlink [PDF08]. This attempt is also known as multiple transmit / multiple receive (MTMR). In this section a method is presented to take advantage of the constellation of neighbouring base stations (BSs) serving the same area, namely their cell borders and the knowledge of the user terminal positions, see Figure 3-1. The methods apply transmit diversity techniques within these broadcasted regions. This results in a further source of diversity in addition to the existing macro diversity in such broadcasted areas. Therefore, macro diversity and transmit diversity techniques are combined which transform to cellular diversity [Pla08]. Two transmit diversity techniques can be applied by using adjacent BSs: Cyclic delay diversity (CDD [DK01]) resulting in cellular CDD (C-CDD) and space time block coding (i.e., Alamouti coding [Ala98]) resulting in the cellular Alamouti technique (CAT). Within these two proposed MTMR techniques a radio resource management (RRM) over the sub-carrier resource is possible because the underlying OFDMA transmission technique exclusively assigns the sub-carrier resources to one user.

![Figure 3-1: Mobile user at the cell border with influence from neighbouring base stations.](image)

The signalling structure, principles, benefits and also drawbacks of C-CDD and CAT were already discussed in detail in Deliverable D3.1 “Physical Layer Enhancements using Localisation Data” [D31].

3.1.1 Impact of Cellular Diversity on the Link Level

In [D31] the bit error rate performance on the link level was investigated. Here, the resulting throughput of the advanced cellular systems using cellular diversity techniques is investigated to identify the impact of the applied techniques. These investigations are limited to the higher medium access control (MAC) layer automatic-repeat-request (ARQ) scheme [LCM84]. By using all available sub-carrier resources, the system has a maximum throughput of

$$\eta_{\text{max}} = M_{\text{mod}} R \frac{N_C}{T_s \frac{1}{B}}, \quad (3.1)$$
where $M_{\text{mod}}$ is the cardinality of the used modulation alphabet, $R$ is the used code rate, $N_c$ is the number of used sub-carriers, $T_s$ is one OFDM symbol duration, and $B$ is the used bandwidth.

We assume that the total number of sub-carriers is equally distributed by the maximum number of users per cell, each user has a maximum throughput of $\eta_{\text{max}}$. The throughput $\eta$ of the system, using the probability $P(k)$ of the first correct frame transmission after $k-1$ failed retransmissions, is given by

$$\eta = \sum_{k=0}^{\infty} \frac{\eta_{\text{max}}}{k+1} P(k) \geq \eta_{\text{max}} (1 - \text{FER}),$$  \hspace{1cm} (3.2)

A lower bound of the system is given by the right hand side of Error! Reference source not found. by only considering $k=0$ and the frame error rate (FER). This lower bound will be investigated in this chapter.

### 3.1.2 Exploitation of the Positioning Information for Cellular Diversity

Users with similar demands in the broadcasted region can benefit from the two techniques. Inter-BS communication is necessary to guarantee the transmission of the desired signals. Therefore, information of the user position would be very beneficial to initialize the cellular diversity techniques at neighboring BSs beforehand. Furthermore, with a positioning information power adaptive transmission schemes can be applied to broaden the diversity area at the critical cell border. This positioning dependent transmit power adaption of the desired signal from both base stations is described in more detail in [D31].

### 3.1.3 Methodology, Assumptions, and Assessment Criteria

#### Methodology:

The cellular diversity techniques are applied in a multiple cellular environment with two involved cells. The performance results are given for one desired user in terms of its possible throughput by using an ARQ scheme.

#### Assumptions:

- From WP2 input regarding the position accuracy of a mobile user can be used to initiate the cellular diversity technique beforehand. The more precise the position information the better the adaptation will be. On the other side the information about the existing environment is also necessary, e.g., there will be a total blocking of one of the cellular diversity signals. Therefore, it is meaningful to start the initialization of the cellular diversity techniques. Furthermore, a regular update of the position information is necessary to apply an efficient power adaptation of the transmitted signals.

#### Assessment criteria:

Two cases of evaluations exist. The first compares the performance of a cellular system without any cellular diversity techniques with a system with cellular diversity. The second case includes a perfect updated information of the position, and therefore, transmit power adaptation can be applied on top of the cellular diversity to broaden the received diversity area.

### 3.1.4 Evaluation

#### 3.1.4.1 Simulation Setup

The simulations are based on the downlink and the following system parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency:</td>
<td>5 GHz</td>
</tr>
<tr>
<td>Signal bandwidth:</td>
<td>82 MHz</td>
</tr>
<tr>
<td>subcarrier spacing</td>
<td>49 kHz</td>
</tr>
<tr>
<td>FFT length:</td>
<td>2048</td>
</tr>
<tr>
<td>Subcarriers:</td>
<td>1664</td>
</tr>
<tr>
<td>One user occupies</td>
<td>208 sub-carriers</td>
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<tr>
<td>OFDM symbol duration</td>
<td>20.48 μs</td>
</tr>
<tr>
<td>OFDM symbols per frame</td>
<td>16</td>
</tr>
<tr>
<td>Guard interval length</td>
<td>128</td>
</tr>
<tr>
<td>convolutional code with rate</td>
<td>$\frac{1}{2}$; (561; 753)oct</td>
</tr>
<tr>
<td>modulation:</td>
<td>4-QAM</td>
</tr>
<tr>
<td>SNR of</td>
<td>5dB</td>
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<tr>
<td>perfect channel state information at the receiver</td>
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<tr>
<td>For C-CDD:</td>
<td>the cyclic delay is set to 30 samples</td>
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Environment parameters:

<table>
<thead>
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<tr>
<td>Cell radius is $d$</td>
<td>300m</td>
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<tr>
<td>Cellular environment</td>
<td>2-cells</td>
</tr>
<tr>
<td>Propagation path loss with decay factor of 3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Channel model:</td>
<td>IEEE 802.11n [IEEE04], representing large open space (indoor and outdoor)</td>
</tr>
<tr>
<td>Statistically independent channels with equal stochastic properties from each BS</td>
<td></td>
</tr>
<tr>
<td>Normalized transmission power</td>
<td></td>
</tr>
<tr>
<td>Perfect Radio Resource Management for the desired user</td>
<td></td>
</tr>
</tbody>
</table>

**Difference between C-CDD and CAT simulation setup**

Instead of a fully inner interleaving of the OFDM symbols on one OFDM frame (two-dimensional (2D) interleaver) in C-CDD, for CAT the simulation chain includes only a frequency interleaver (one-dimensional (1D) interleaver) to maintain the time non-selective constraints of the Alamouti coding. Since a mobile radio channel is more likely to be time non-selective, i.e., the fading is almost constant during two successive symbols. With a 2D interleaver the quasi-static assumption of the fading would be violated. Therefore, the simplicity to decode the Alamouti code would be destroyed.

**3.1.4.2 Results**

In the following simulation results for the applied cellular diversity techniques in a two-cell scenario will be given. Figure 3-2 represents the frame error rate (FER) versus the distance, in meters, of the mobile user to the desired BS. The cell border is at 300m and the chosen modulation alphabet is 4-QAM.

The throughput performances of the applied cellular diversity methods are compared with the OFDMA reference system using no transmit diversity technique and with a random independently chosen sub-carrier allocation in each cell site. The reference system is half and fully loaded. We observe a large performance gain in the close-by area of the cell border ($d = 300$) for the proposed cellular diversity techniques. C-CDD enables an additional substantial performances gain compared to pure macro diversity which transmits the identical signals from both cell sites without any cyclic delay. There exists a drawback of C-CDD due to the interaction between the artificial included delay and the inherent geographical delay. These two delays cancel out each other and transmit diversity vanishes that can be seen at $d=345m$. This characteristic could also be recognized by the pure bit error rate evaluations in [D31]. For CAT a larger throughput gain is achieved in the cell border area compared to C-CDD. CAT exploits more additional transmit diversity at the mobile terminal on top of the already existing macro diversity.

**3.1.5 Conclusions**

Since both BSs for the cellular diversity techniques transmit the signal with the same power as the single BS in the reference system, the received signal power at the mobile terminal is doubled. In the inner cell, the cellular diversity technique lack the diversity from the other BS, and therefore, the performance merges to the reference performances. To establish a more detailed understanding we analyze the cellular diversity techniques with halved transmit power. For this scenario, the total designated received power at the mobile terminal is equal to the conventional OFDMA system. Still, the throughput performance with halved transmit power is better than the performance of the reference system.
Furthermore, the adaptive transmit power strategy is investigated and is compared with the throughput performances by using a constant halved transmit power in the following simulation results. Figure 3-3 represents the performance evaluation of the C-CDD technique. There is still a performance gain due to the exploited transmit diversity for $d=\{250\ldots350m\}$. The performance characteristics are similar as in the full transmit power mode (except the missing performance degradation due to the inherent delay cancel out each other). The pure macro diversity scenario at the cell border also represents the conventional OFDMA single-user case without any inter-cellular interference. Each BS is restricted to a maximum transmit power in a regulated cellular system. For the adaptive transmit power scheme depending on the user’s position the received diversity and the resulting performance gain are increased in a wider area around the cell border. In contrast to the non-adaptive C-CDD with halved transmit powers at both BSs, the power adaptation guarantees the reception of the signal with maximum power throughout the whole cell.

For CAT, similar performance characteristics are achieved. Despite the halved transmit power from both BSs Figure 3-4 shows still a larger performance gain in the cell border area for CAT. Also the transmit power adaptation (depending on the position of the mobile user) broadens the received diversity area. On the other side, CAT requires a more complex channel estimation process than C-CDD. This will result in a loss of the throughput performance compared to C-CDD [Pla08] which is not taken into account in these investigations yet.

The decision for using the adaptive power transmission is given at $d=225m$ for C-CDD and $d=200m$ for CAT.

---

**Figure 3-2: FER versus distance of mobile to the desired BS in meters for a SNR = 5 dB using cellular diversity techniques (C-CDD and CAT) with full / halved power and no transmit diversity technique.**
Figure 3-3: FER versus distance of mobile to the desired BS in meters for a SNR = 5 dB using C-CDD with halved and adaptive transmit power and no transmit diversity technique.

Figure 3-4: FER versus distance of mobile to the desired BS in meters for a SNR = 5 dB using CAT with halved and adaptive transmit power and no transmit diversity technique.
4 Radio Resource Management for OFDM based systems

4.1 Dynamic Resource Allocation policies for WiMAX

4.1.1 Introduction

The cost-effective delivery of Triple play applications (video, audio and data) in a ubiquitous and seamless manner are expected to be the main drivers of B3G networks, placing highly stringent constraints on both high data rate transmission and Quality of Service (QoS) demands. Therefore, it is important to investigate techniques that can maximize spectral utility by efficiently managing the radio resources for heterogeneous packet-based services. The main objective of the WHERE project, is to exploit positioning information as well with communication techniques to improve this objective. So a Radio Resource Management that exploits positioning information can outperform conventional communication systems. Fundamental to resource management is packet scheduling. An efficient scheduling policy must exploit cross-layer information from the PHY layer as well as from higher layers, to provide efficient mapping of data blocks onto the available transport channels within the Medium Access Control (MAC) layer, whilst providing the requested quality of service (QoS) in a heterogeneous service environment [Shak03, Kopp95]. In order to cater for fairness, efficiency in resource usage and QoS provisioning, different variations of Opportunistic Scheduling have been proposed. The Proportional Fairness scheduler (PF) algorithm is widely used in 1xEV-DO, also named HDR networks [Kopp95]. The algorithm selects the user, among all backlogged users, which has the best feasible data rate normalized by the average throughput over a sliding window filter.

In this section we present the packet scheduling algorithm fully aligned with this cross-layer paradigm, and specifically designed around an adaptive DRA architecture framework for the OFDMA multiple access scheme adopted by the IEEE 802.16e, also called Mobile WiMAX [802.16e05]. A key principle of our DRA is the exploitation of the inherent system diversities in various domains through the intelligent management of the allocation and access of users to the available radio resources.

4.1.2 Proportional Fair scheduling in WiMAX system

This family of schedulers prioritizes users according to their potential revenue if serviced. Typical utility schedulers attempt to maximize the total system utility. The typical approach is to select packets from queues in order to maximize the following metric [Ryu05, Lei07]:

\[
i(k) = \text{arg} \max_{i=1,...,N} \frac{R_i(k)}{T_i(k)}
\]

Where:
- \( T_i(k) \) is the average throughput for the \( i \)th user
- \( R_i(k) \) is the bit rate achieved with the actual channel state.

4.1.3 WiMAX DRA Architecture

A system level simulator that models the salient features of the WiMAX standard IEEE802.16e [802.16e05, WF09, AJA08] was developed. The simulator implements the DL communication in a PMP configuration using the TDD mode of transmission. In the MAC frame, resources are available in both frequency (sub-channels) and time domains (OFDM symbols). The smallest granularity of resource allocation in the time and frequency domains is the slot. The size of the slot depends on the type of sub-channelization mode and on the direction of transmission. A burst is a rectangular allocation of a group of slots with the same modulation and coding scheme (MSC) belonging to the same or different users. In our simulations each packet is mapped into a group of contiguous slots forming a burst intended to a single user provided the same modulation and coding scheme is followed in the transmission of all packets allocated to it. Each burst contains only one MAC PDU (to which a single packet is mapped into). The MAC PDU is segment into forward error correction (FEC) blocks that are coded and interleaved within the burst.

In the implemented DRA, Partial Usage sub-channelization Scheme (PUSC) was used. In PUSC sub-channels are realized using a distributed sub-carrier permutation method that pseudo-randomly draws sub-carriers to form a sub-channel and used to achieve frequency diversity in cases where the mobile
speed makes it difficult or inefficient to track frequency-selective channel variations. For further details regarding the SINR modelling, Link Level Interface and Link Adaptation schemes please refer to [AJA08].

Figure 4-1 is a schematic representation of the proposed DRA scheme for the WiMAX standard. The packet scheduler creates a list sorted by the decreasing order of the priority metric. Packets achieving the maximum delay bound for the service are dropped in the BS. The Resource Allocator assigns slots for the packets remaining in the buffer of the selected user. The process continues until there are no packets for transmission or no slots available in the map of resources. Each burst is assigned a free HARQ channel that uses type II Chase Combining. The whole transmission process elapses along a cycle equivalent to two frames. Feedback channels (HARQ and CQICH) are assumed to be transmitted in the uplink sub-frame of the same frame in which the corresponding downlink transmission occurred.

In the simulations all users experiencing a bad channel condition, i.e., those users reporting a CQI value which do not allow the selection of the most robust MCS scheme, are not considered in the scheduling process. The idea is to limit the amount of packets received in error due to bad channel quality.

### 4.1.3.1 Channel Models

Fast fading is generated by a modified Jakes model where the carrier frequency and the mobile speed are used for fast generation of independent Rayleigh faders [Li00]. In the simulation a wideband SISO channel model is implemented by a six tapped delay model, according to the Pedestrian-B 3km/h channel model for the serving sectors of the central BS. A flat fading channel is assumed for neighboring cells.

Bi-dimensional log-normal shadowing is generated at the beginning of each run $i$ [Cai03]. The shadowing $SH(x,y,j)$ in DB between one $MS(x,y)$ and one BS $j$ is the sum of two variables:

$$SH(x,y,j) = \sqrt{0.5\left(F_0(x,y) + F_j(x,y)\right)}$$  \hspace{1cm} (4.2)

Where $F_0(.)$ and $F_j(.)$ are spatial functions generated using the method described in [Cai03]. They have a Gaussian distribution with zero mean and $\sigma_{shad}$ standard deviation and a spatial correlation given by:

$$R(d) = e^{-\ln2d/\text{DecorrLen}}$$  \hspace{1cm} (4.3)

Where $d$ the distance between two is points and $\text{DecorrLen}$ is the shadowing de-correlation length.

The path loss model is the modified COST231 Hata for the urban macrocell at a carrier frequency $f$ [GHz] between 2 and 6 GHz, assuming the BS and MS heights of 32m and 1.5m respectively, and is given by:
Using the aforementioned channel models, the SINR (Signal-to-Interference-plus-Noise Ratio) of each OFDM sub-carrier is computed according to the approach:

\[
\gamma_k = \frac{I_{dc}}{I_{dc} + N_o} \frac{N_{\text{used}}}{N_d + \text{PDR}_P} H_k
\]

(4.5)

Where \( N_{\text{used}} \) is the total number of sub-carriers, PDR is the Pilot-to-Data sub-carriers power ratio and \( N_d \) is the number of data sub-carriers per OFDM symbol, for the PUSC channel mode. \( N_o \) is the receiver thermal noise power and \( I_{dc} \) is the other-cell interference power density, assumed spatially and temporarily uncorrelated. It is assumed that neighbouring cells transmit with maximum power, i.e. with full load.

The gain of the \( k^{th} \) sub-carrier is computed according to the recommendations of as follows:

\[
H_k = \sum_{p=1}^{N_{\text{used}}} M_p A_p e^{j \theta_p} e^{-2j\pi T_p k f_p}
\]

(4.6)

Where \( p \) represents the multi-path index for the Ped. B channel model \( A_k \) is the amplitude value corresponding to the long-term average power for the \( p^{th} \) path of this same channel model \( f_k \) is the relative frequency offset of the \( k^{th} \) sub-carrier of the specific FUSC sub-channel and \( T_p \) is the relative time delay of the \( p^{th} \) path.

In the receiver, post-processing of the signals received from the serving and interfering BSs is performed. For a Single-Input-Single-Output (SISO) architecture and a matched filter in the receiver, the received signal at the \( k^{th} \) sub-carrier for the target user is computed according to:

The transmission of a coded block over different sets of sub-carriers results in a number of SINR measures that equals the number of sub-carriers sets, which can be quite high. Hence, data compression is mandatory. The coded symbol SINR in sub-carrier \( k \) is given by:

\[
\text{SINR}^{[r]} = \frac{\sum_{j=1}^{N} p_{j}^{(r)} p_{j,\text{loss}}^{(r)} H^{[r]}[k]^2}{\sum_{j=1}^{N} p_{j}^{(r)} p_{j,\text{loss}}^{(r)} H^{[r]}[k]^2 + \sigma_n^2}
\]

(4.7)

Where \( N \) is the number of interferers, \( P_{j}^{(r)} \) is the transmit power per slot for the \( j^{th} \) cell, \( P_{j,\text{loss}}^{(r)} \) is the distance dependent path loss, including shadowing and antenna gains/losses, \( H^{[r]}[k] \) is the channel gain for the desired MS from the \( j^{th} \) cell and for the or the \( k^{th} \) sub-carrier, \( X^{[r]}[k] \) is the transmitted symbol by the \( j^{th} \) cell at the \( k^{th} \) sub-carrier, \( N^{[r]}[k] \) is the thermal noise at the received, modelled as AWGN with zero mean and variance \( \sigma_n^2 \).

The set of coded symbols SINRs are mapped onto a single value named the Effective SINR value. This value can be used to match AWGN Look-Up Tables (LUTs). The EESM expression determines how the effective SINR is obtained from the multiple SINR’s on the different subcarriers:

\[
\text{SINR}_e = -\beta \ln \left( \frac{1}{P} \sum_{p=1}^{P} S_{P,n}^{(r)} \beta \right)
\]

(4.8)

Where the parameter \( \beta \) is to be optimized for every link mode (MCS) based on link level simulation results.

### 4.1.4 User Quality Tracking

Periodically the SIR measurement performed by each MS, \( y_n(MS) \), using the symbol of the preamble is reported and is available at the BS at \( n T_{\text{CQI}} \) (\( T_{\text{CQI}} \) is the reporting period). Every \( T_{\text{CQI}} \) the quality of the channel is updated combining the past information and the new value \( w_n(MS) \) provided by these measurements, according to the time-smoothing filter:

\[
CQI_k(MS) = 0.7 w_n(MS) + 0.3 CQI_{k-1}(MS)
\]

(4.9)
4.1.4.1 Traffic Models

Simulations were carried out using the NRTV64 traffic model [ETSI98]. This traffic model periodically generates packets of variable sizes which compose a frame of video data arriving at a regular interval of $T$ seconds. The NRTV traffic model is a bursty traffic model with an average source bits rate of 64Kbps. The parameters used in the NRTV traffic model are listed below.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Distribution</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-arrival time between frames</td>
<td>Deterministic</td>
<td>100ms</td>
</tr>
<tr>
<td>Number of packets/frame</td>
<td>Deterministic</td>
<td>8</td>
</tr>
<tr>
<td>Packet size</td>
<td>Truncated Pareto (Mean: 50, Max: 125 (bytes))</td>
<td>$K=20$ bytes, $\alpha = 1.2$</td>
</tr>
<tr>
<td>Inter-arrival time between packets</td>
<td>Truncated Pareto (mean: 6, Max: 12.5 (ms))</td>
<td>$K=2.5$ms, $\alpha = 1.2$</td>
</tr>
</tbody>
</table>

4.2 Channel Quality Estimation for Scheduling using Positioning Information

Scheduling is an important issue on Radio Resource Management of 3rd Generation and Beyond. The scheduler can take many shapes and forms. More sophisticated schedulers will have a selection of requirements, that tries to provide a weighting to each user queue i.e. $W = f($User QoS, Maximization of channel throughput, fairness). Maximization of the channel throughput follows the ability of the system in estimating and predicting the channel state conditions in the period of transmitting packet. Fast scheduling has been introduced in HSDPA and its improvement can be obtained exploiting positioning information namely if channel positioning information can be use for future channel estimation. In this section we propose to investigate the performance of the WiMAX system where the DRA will use the channel estimated based on positioning information. More detailed, the SIR in the transmission interval will be estimated using previous SIR values and positioning information.

4.2.1 Packet based Scheduling Systems

As indicated by the 3GPP standards [TR25922], the Radio Resource Management (RRM) strategies for HSDPA foresees that packet scheduling functionality performed by MAC-hs is tight-coupled with Adaptive Modulation and Coding (AMC) to the radio channel conditions, where all the issues are executed during single transmission period. Hybrid ARQ and retransmissions are used due to the dynamics of the mobile radio channel, since there is always a delay between the interval that the packet is scheduled and the interval the packet is transmitted, as depicted in Figure 4-2. The hybrid ARQ transmission protocol assume four periods, including channel estimation (1), scheduling (2), broadcast of transmission information such as modulation and user (3), and transmission (4).

![Figure 4-2– Delay between channel estimation and transmission intervals.](image)

The PFS scheduling, as the name says, tries to impose fairness among the users and is represented previously by the equation (4.1)

Since transmission parameters are adapted to the channel state, $R_i(k)$ in the (4.1) depends on the selected modulation and is given using the Channel Quality Indication (CQI). $R_i(k)$ estimation can be given as indicated by (4.9)

$$R_i(k) = [1 - BLER(CQI_i(k), MCS(k))] \times \frac{BlockSize(MCS(k))}{TTI}$$

$$\text{(4.10)}$$
Where $BLER(CQI_i(k), MCS(k))$ is the Block Error Rate associated to the Channel Quality Indication (CQI) and the Modulation and coding scheme used (MCS). BlockSize is the quantity of data that with the selected Modulation and Coding scheme can be transmitted during the Transmission Time Interval (TTI).

### 4.2.2 Channel Quality Estimation using Positioning information

#### 4.2.2.1 Channel Quality Indication using averaging window

In previous section was presented the particularities related to the scheduling process in 3G and beyond 3G systems, where the accuracy in the channel estimation is responsible for success of correct modulation selection, minimizing the number of packets retransmissions. To minimize the number of retransmission of a packet filters are used to shape the CQI values used during the modulation selection. The simplest way to achieve this is averaging the Signal to Interference Plus Noise Ratio SINR in a window period.

Equation (4.10) presents a filtering method for CQI estimation in a HSDPA system level simulator used by IT.

$$CQI_i(k) = 0.7 \times SINR_i(k) + 0.3 \times \frac{\sum_{w=1}^{W} SINR_i(k-w))}{W}$$  \hspace{1cm} (4.11)

This filter weights the actual value of SINR on 70% and SINR measured in previous transmissions on 30% for the CQI estimation. In this method a window of W TTI is used.

#### 4.2.2.2 Channel Quality Indication using positioning information

IT proposes an improved method for such algorithm, where positioning information is used. Positioning information can easily be predicted following the movement pattern. And this positioning information can be used to track the fast fading channel.

The proposed method of channel prediction is to use the Least Mean Square method presented in the Figure 4-3.

![Figure 4-3– LMS Implementation Using FIR Filter.](image)

For LMS estimation previous values of SIR is used, and positioning information and direction change pattern is used for the fast fading correlation.

### 4.2.3 Methodology, assumptions and evaluation criteria

#### 4.2.3.1 Simulation Scenario

The system level performance evaluation methodology is based on the draft evaluation proposal for IEEE802.16. Simulations are carried out using a combined snapshot-dynamic mode, where in each simulation run (of a total of $N_{run} = 5$ independent dynamic runs) $N_{user}$ users are randomly uniformly distributed over a hexagonal network of tri-sectored cells composed of three tiers of 19 BSs with 3 sectors.
each. Each simulation run lasts for $T_{run} = 75000$ frame periods. User positions were updated on every run and for each MS-BS pair, a random shadowing value is drawn whilst mobile positions, shadowing and path loss values are kept constant for the whole simulation duration. A full load scenario is assumed where all BSs around the central cluster are assumed as transmitting with maximum power all the time. They are considered for DL interference only on the central BS, which is the only one simulated. In each frame interval the following events are performed: packets are generated according to the NRTV64 traffic model; the fast fading channel is updated; DRA executed and packet quality detection is performed. During the packet quality detection, the received block SIR of the packet is computed and mapped to the corresponding BLER using the link interface. A random variable $u$ uniformly distributed between 0 and 1 is drawn. If $u < BLER$ the packet is assumed as erroneous and a NACK message is feedback to the serving BS on the CQICH of the uplink subframe, otherwise the packet is assumed as correct and an ACK message is sent. The ACK or NACK message is assumed to be received within the uplink portion of the same TDD frame (uplink sub-frame) in which data is initially transmitted or retransmitted.

4.2.3.2 Performance Metrics

The following metrics were used to quantify system level performance:

**Average Service Throughput per MS:**

$$R_{serv}^i = \frac{b_i}{T}$$

Where $b_i$ the total amount of bits is correctly received by the MS $i$ over the whole simulated time and $T$ is the simulation elapsed time.

**Average Transfer Delay per MS:**

$$T_D^i = \frac{1}{N} \sum_{n=1}^{N} T_D^i(n)$$

Where $T_D^i(n)$ is the transferred delay associated to the $n^{th}$ packet successfully received by user $i$. This is the average packet transfer delay for all packets received with success by the mobile.

95-percentile of the CDF of the transfer delay per user

This corresponds to the 95-percentile of the delay from the CDF of all packets transferred delays for each user in the system.

**Average Packet Error Rate per user:**

$$PER^i = \frac{N_{Correct}^i}{N}$$

Where $N_{Correct}^i(n)$ is the total amount of packets received with success by the user.

4.2.4 Simulation Results

To collect results we intend to perform simulations for 50, 60, 70, 80 and 90 users for Max CI and proportional fair scheduling with above system configuration, showing plots of the evolution of the average packet delay vs. the number of users in the system. Also we intend to collect the average packet error rate vs. no. of users. Plots of the 95th percentile of the CDF of all packets delays and the average packet delay for all users will as well being collect.

4.3 Conclusions

In this chapter we propose to investigate the performance of the WiMAX system where the DRA will use the channel estimated based on positioning information. The proposed system will be evaluated using the Proportional Fair Scheduling (PFS) policy and the channel on the instant of the transmission for link adaptation, is estimated based on the evolution of both channel and positioning information. Least Mean Square (LMS) can be the method for track the evolution of the channel. Both the channel states as well as the packet delay are considered in the scheduling process. Performance metrics which includes the cost of deferring the transmission for other users is considered for system evaluation. As well, an innovative and complete cross-layer DRA architecture for the Mobile WiMAX standard using a packet based scheduler is fully described.

5 Positioning for Cognitive Radio

5.1 Introduction

Federal Communications Commission (FCC) frequency allocation table revealed that the number of wireless services has grown almost exponentially over the last twenty years [FCC03]. Spectrum allocation bodies such as FCC in US and Ofcom in UK warned that the rapid development of wireless
systems has resulted in severe shortage of the primary radio spectrum. Meanwhile, traditional fixed spectrum management resulted in inefficient utilization of the radio spectrum [Tafazolli06]. All of these motivated a dynamic and flexible framework for spectrum and radio resource management referred to as cognitive radio.

The original idea of cognitive radio presented in the article [Mitola99] conveys a general framework, whereby a wireless system or device utilizes any available network side information such as channel conditions, codebooks, and even messages communicated between existing wireless devices to determine the efficient strategy of spectrum sharing. Utilizing advanced signal processing and dynamic spectrum allocation policies, cognitive radio techniques support new wireless users operating in the allocated spectrum, without degrading performance of existing primary users.

In the last decade, the majority of research effort was paid for spectrum sensing cognitive radio (SSCR), which is one of special paradigm of the general cognitive radio. The idea came about the fact evident by FCC [FCC02] that there exist temporary spectrum holes in both the licensed and unlicensed frequency bands. Cognitive receivers periodically sense the radio spectrum, and perform opportunistic frequency reuse over the spectrum holes to improve the spectral efficiency. Recently, an overlay cognitive radio technique has been presented in the literature [Maric07]. Cognitive transmitters intelligently utilize all available network side information to perform optimum frequency reuse over the entire frequency band. However, there are many problems remain unsolved in the area of information theory.

The primary focus of this Chapter is about another paradigm of cognitive radios referred to as interference-awareness cognitive radio (IACR). Figure 5-1 depicts an example of the smallest IACR networks accommodating one primary link and one cognitive link which is often referred to as secondary link in literatures. An extreme case for the secondary link to reuse the frequency band occupied by the primary link is that the channel gain between the secondary transmitter and the primary receiver is null. However, there is no such an extreme case in practice. In the IACR paradigm, cognitive users utilize channel side information to evaluate the interference potentially caused by the cognitive transmitter to primary receivers. Communication between cognitive users occurs only if the interference power is below an acceptable threshold. This case is defined as the spatial spectrum hole that offers the opportunity for frequency reuse. The problems this work seeks to address are mainly in two folds:

1) With the availability of channel side information, what is the channel capacity of the IACR paradigm in the Gaussian channel? Moreover, what is the optimum power setup at the secondary transmitter? These problems will receive a careful investigation in Section 5.3 III.

2) The process of estimating channel between the secondary transmitter and the primary receiver interferes with the primary communication. This motivates us to utilize localization information to determine the spatial spectrum hole for frequency reuse. This technique will be addressed in Section 5.4IV in terms of outage probability and efficient power control.

Remark: The technical contents of this chapter are based on the smallest cognitive radio network as depicted in Figure 5-1 so that our primary focus is on the fundamental issue in the area of network information theory.
5.2 Mathematical Description of IACR

Consider the situation where the primary transmitter sends information $x_1$ with the power $P_1$ to its corresponding receiver via the communication channel $a_{11}$. The received information at the primary receiver is expressible as

$$\tilde{y}_1 = a_{11}x_1 + v_1$$

(5.1)

where $v$ is the additive white Gaussian noise with zero mean and variance $N_o$. The achievable rate of this communication (denoted by $R_{11}$) is upper bounded by the Shannon capacity, i.e.,

$$R_{11} < C[(Pa_{11}^2)/(N_o)], \quad C(x) = \frac{1}{2}\log_2(1+x).$$

Meanwhile, the secondary transmitter wants to reuse the same frequency band to send the information $x_2$ with the power $P_2$. The secondary communication occurs under the following condition

$$P_2a_{21}^2 < \eta$$

(5.2)

where $a_{21}$ is the channel gain between the secondary transmitter and the primary receiver, and $\eta$ the power threshold. In the situation of coexistence, the received information at the primary receiver $\tilde{y}_1 = a_{11}x_1 + v_1$ (5.1) is replaced by

$$y_1 = a_{11}x_1 + a_{21}x_2 + v_1.$$  (5.3)

The threshold $\eta$ is carefully chosen so as not to influence considerably the capacity of the primary communication, i.e.,

$$\Delta C = C\left[\frac{Pa_{11}^2}{N_o}\right] - C\left[\frac{Pa_{11}^2}{\eta + N_o}\right] < \varepsilon$$

(5.4)

where $\varepsilon$ is a carefully chosen threshold that dominates the threshold $\eta$. On the other hand, the secondary receiver gets the information as below

$$y_2 = a_{12}x_1 + a_{22}x_2 + v_2$$

(5.5)

where $a_{12}, a_{22}$ stands for the channel gain between the secondary receiver and the transmitters, respectively. Then, what is the maximum achievable rate of $x_2$ in various wireless situations? What is the optimum setup of $\varepsilon$? These questions need a satisfactory answer in the area of information theory.

5.3 Capacity Theorems with Channel Side Information

This section aims to investigate Shannon capacity of the secondary link with respect to two aspects. One aspect is about the situation described by equations (5.3) and (5.5) while the other is about the situation, where the interference is completely removable, i.e., interference-free equivalent scenario.

5.3.1 Achievable rate for a given threshold

Eqn. (5.5) formulates a multiple-access environment, where $x_2$ is the wanted information. If the secondary receiver deals with $x_1$ as noise, the achievable rate of $x_2$ is limited by

$$R_2 = I(x_2,y_2) < C\left[\frac{P_2a_{22}^2}{P_2a_{22}^2 + N_o}\right]$$

(5.6)

where $I(\cdot)$ denotes the mutual information. If the secondary receiver deals with $x_1$ as message, the capacity region of this multiple access channel is given by [Cover06]
\[
\begin{cases}
R_1 < C \left[ \frac{P a_{11}^2}{\eta + N_o} \right]
\cup
R_2 = I(x_2; y_2 | x_1) < C \left[ \frac{P a_{22}^2}{N_o} \right],
\end{cases}
\]
\[R_1 + R_2 = I(x_1, x_2; y_2) < C \left[ \frac{P a_{12}^2 + P a_{22}^2}{N_o} \right] \]  
(5.7)

Since the secondary communication does not influence the maximum achievable rate of the primary communication, the capacity region (5.7) indicates that the communication rate \( R_2 \) fulfills the following result

\[R_2 < R_2^{(MAC)} = \min \left( C \left[ \frac{P a_{22}^2}{N_o} \right], C \left[ \frac{P a_{12}^2 + P a_{22}^2}{N_o} \right] - C \left[ \frac{P a_{11}^2}{\eta + N_o} \right] \right). \]  
(5.8)

As a summary of (5.6) and (5.8) the achievable rate for a given threshold \( \eta \) is

\[R_2 < \max \left( C \left[ \frac{P a_{22}^2}{P a_{12}^2 + N_o} \right] R_2^{(MAC)} \right). \]  
(5.9)

Further calculation of (5.9) leads to the following result:

**Theorem 1**: Given the channel condition \( a_{12} < a_{11} \) the maximum achievable rate of the secondary link is given by (5.6)

Otherwise, the maximum achievable rate is

\[R_2 < C \left[ \frac{P a_{22}^2}{N_o} \right] - C \left[ \frac{P a_{11}^2}{\eta + N_o} \right], \]  
(5.10)

for the channel condition \( a_{11}^2 < a_{12}^2 < a_{11}^2 + (P a_{22}^2) / N_o \), and

\[R_2 < C \left[ \frac{P a_{22}^2}{N_o} \right] \]  
(5.11)

For \( a_{12}^2 > a_{11}^2 + (P a_{22}^2) / N_o \).

**Proof**: Abbreviation.

### 5.3.2 Achievable rate for interference-free equivalent scenario

In fact, eqn. (5.3) formulates a multiple-access channel. The primary receiver can reconstruct \( x_2 \) without causing rate penalty to \( x_1 \) only when the following condition holds \[Carleial75\]

\[R_2 < C \left[ \frac{P a_{22}^2}{P a_{11} + N_o} \right] < C \left[ \frac{\eta}{P a_{11} + N_o} \right]. \]  
(5.12)

In addition to Theorem 1, (5.12) gives another upper bound of \( R_2 \). Therefore, the overall capacity limit of the secondary link is formulated by

\[R_2 < \max \left( C \left[ \frac{P a_{22}^2}{P a_{12}^2 + N_o} \right] R_2^{(MAC)}, C \left[ \frac{\eta}{P a_{11} + N_o} \right] \right). \]  
(5.13)

The original proposal of IACR (5.4) indicates that \( \eta \) is so small that the upper bound (5.13) reduces to (5.9).
5.3.3 Optimum power control at the secondary transmitter

The proposed power allocation is optimized for the capacity results provided in Theorem 1. The first condition to configure $P_2$ is to meet the capacity difference $\epsilon$. This condition can be obtained by plugging $\eta = P_2 a_{21}^2$ into (5.4), i.e.,

$$P_2 < \frac{(4^\epsilon - 1)(P_1 a_{11}^2 / N_o + 1)N_o}{(P_1 a_{11}^2 / N_o + 1 - 4^\epsilon)a_{21}^2}. \quad (5.14)$$

Joint consideration of this result with Theorem 1 leads to the following result:

Theorem 2: Given the channel condition $(a_{12}^2) > (a_{11}^2 + (P_2 a_{22}^2) / N_o)$, the transmit-power at the secondary transmitter is upper bounded by

$$P_2 < \min\left(\frac{(4^\epsilon - 1)(P_1 a_{11}^2 / N_o + 1)N_o}{(P_1 a_{11}^2 / N_o + 1 - 4^\epsilon)a_{21}^2}, \frac{(a_{12}^2 - a_{11}^2)N_o}{a_{12}^2}\right). \quad (5.15)$$

Otherwise, (5.14) is the upper bound of $P_2$.

Proof: Abbreviation.

5.4 Location-Assisted Coexistence Strategy

Section 5.3 shows that the IACR technique requires the channel side information. In particular, the secondary transmitter needs the channel knowledge $a_{11}$, which is the key to determine whether to reuse the frequency band and how much power to spend. Basically, there are two channel estimation strategies that can be utilized to obtain this parameter. For the first strategy, the primary receiver performs estimation $a_{21}$ and feeds the parameter back to the secondary transmitter. In this case, the secondary transmitter needs to send data to the primary receiver for the purpose of channel estimation. However, the rate achievability of the primary link is considerably influenced due to the feedback overhead and the channel estimation process. For the second strategy, the secondary transmitter is responsible for the channel estimation, and the primary receiver temporarily becomes a transmitter. This is suitable for the situation, where the primary link operates in the time-division duplexing (TDD) fashion. However, the secondary link has to wait for the reverse communication of the primary link, which results in significant processing delay and overall network inefficiency. Therefore, to bypass the estimation of $a_{21}$ motivates us to utilize the localization information for the IACR.

In fact, exploiting localization information for cognitive radios is recently proposed in the article [Yarkan08], which delivers a brainstorm about the potential help from positioning systems such as GPS and GNSS to the SSCR. The primary objective of this section is to investigate the localization assisted IACR network from the information-theoretic point-of-view. The investigation is based on the following basic assumptions:

A1) A map is available at the secondary transmitter;
A2) The positioning system informs the secondary transmitter regarding the accurate positions of other relevant network nodes;
A3) The secondary transmitter knows the p.d.f. of the channel

The coexistence strategy is described as follows:

The secondary transmitter performs frequency reuse only when it observes a large shadowing object between the primary receiver and itself (as a typical example shown in Figure 5-1). In this situation, non-line-of-sight (NLOS) propagation environment is assumed for the link between the secondary transmitter and the primary receiver, and thus the p.d.f. of $a_{21}$ is assumed Rayleigh [Rappaport96].

5.4.1 Outage behaviour of the primary communication

Define $\delta_{21}^2 = (P_2 a_{21}^2) / (N_o)$ to be the average signal-to-noise ratio (SNR). $\delta_{21}^2$ is the channel variance.
of the secondary transmitter to the primary receiver link, which can be obtained from the pre-established library of localization-dependent information [Yarkan08]. The secondary communication occurs for the condition

\[
\overline{\gamma}_{21} < \overline{\gamma}_t
\]

(5.16)

where \( \overline{\gamma}_{21} \) denotes threshold of the average SNR. Hence, an appropriate setup of \( \overline{\gamma}_t \) is important to the overall system performance.

The inequality (5.14) shows that the instantaneous SNR \( \gamma_{21} \) is smaller than the threshold

\[
\gamma_t = \frac{(4^\varepsilon - 1)(\gamma_{11} + 1)}{\gamma_{11} + 1 - 4^\varepsilon}
\]

(5.17)

where \( \gamma_{11} = (P_1a_1^2)/(N_o) \). Provided that the SNR \( \gamma_{11} \) is deterministically known, the probability of the event \( (\gamma_{21} > \gamma_t) \) is given by [Simon05]

\[
\mathsf{Pr}(\gamma_{21} > \gamma_t) = \exp\left(-\frac{\gamma_t}{\overline{\gamma}_{21}}\right) < \exp\left(-\frac{\gamma_t}{\overline{\gamma}_t}\right).
\]

(5.18)

If the primary communication requires \( \mathsf{Pr}(\gamma_{21} > \gamma_t) < p_t \), the SNR threshold \( \overline{\gamma}_t \) is obtained as below

\[
\gamma_t = \frac{(1 - 4^\varepsilon)(\gamma_{11} + 1)}{(\gamma_{11} + 1 - 4^\varepsilon)\ln(p_t)}.
\]

(5.19)

This equation also gives an upper bound of the transmit-power at the secondary transmitter.

### 5.4.2 Outage behaviour of the secondary communication

Theorem 2 shows that (5.14) is the upper bound of \( P_2 \) for the channel condition \( (a_{12}^2) < (a_{11}^2 + (P_2a_{22}^2)/N_o) \). In this situation, we can compare (5.19) with (5.14) and find that the capacity outage of the secondary link does not occur only if \( \ln(1/p_t) > 1 \). Hence, the outage probability of the primary communication is upper bounded by

\[
p_t < \exp(-1)
\]

(5.20)

Applying this outage probability in

\[
\mathsf{Pr}(\gamma_{21} > \gamma_t) = \exp\left(-\frac{\gamma_t}{\overline{\gamma}_{21}}\right) < \exp\left(-\frac{\gamma_t}{\overline{\gamma}_t}\right).
\]

(5.18)

results in \( \overline{\gamma}_t > \gamma_t \).

For the channel condition \( (a_{12}^2) > (a_{11}^2 + (P_2a_{22}^2)/N_o) \), the transmit-power \( P_2 \) is upper bounded by (5.15)

In this situation, \( p_t \) needs to be further reduced if the upper bound (5.15) is not the same as (5.14)

Then, the above presentation can be summarized as follows:

**Theorem 3**: Suppose the parameter \( \overline{\gamma}_{21} \) is available, a necessary condition for the secondary communication to occur is \( \overline{\gamma}_{21} < \gamma_t \)

**Remark 1**: Although Theorem 3 only gives a necessary condition, a more strong condition can be obtained by considering \( p_t \) for the specific system requirements.
Remark. 2: If the secondary link does not occur for the condition \( a_{21} > a_{11} \) then the secondary link will not have capacity outage for the condition \( \gamma_{21} < \gamma_1 \).

Remark. 3: Below provides the procedure about how to establish the secondary link with the support of localization information:

![Diagram](image)

**Figure 5-2: the procedure of establishing the secondary link.**

### 5.5 Numerical Results

The primary objectives of numerical analysis are in two folds: 1) to see the fundamental capacity limit of the IACR; 2) to see whether the localization information can offer satisfied performance for the IACR. The following channel parameters are given for the case study: \( a_{11} = 1, \ a_{22} = 1, \ a_{21} = 0.1, \ 0 < a_{12} < 10 \). As shown in (5.14) the transmit-power \( P_2 \) is determined by SNR of the primary link \( P_1/N_o \). Hence, throughout the numerical analysis, the capacity results are always linked with the parameter \( P_1/N_o \).

#### 5.5.1 Test Case 1

![Graph](image)

**Figure 5-3: Capacity of the secondary link as a function of \( P_1/N_o \) and \( \varepsilon \)**

The objective of this test case is to see the relationship between the capacity of the secondary link and the rate penalty to the primary link \( \varepsilon \). In this test, the channel gain \( a_{12} \) is fixed to \( 1e-6 \) and the rate penalty \( \varepsilon \in (0,0.1) \) bit/Hz/sec. The result plotted in Figure 5-3 shows two phenomena: 1) the capacity of the secondary link generally decreases with increase of \( P_1/N_o \), and drops to null for the range (\( > 15 \) dB); 2) the capacity generally increases with increase of \( \varepsilon \) for the SNR range (\( < 15 \) dB). These two phenomena reflects the resource competition behaviour in coexistence environments.
5.5.2 Test Case 2

![Figure 5-4: Capacity of the secondary link as a function of $P_1/N_o$ and $a_{12}$](image)

The objective of this test case is to see the relationship between the capacity of the secondary link and the channel gain $a_{12}$. In this test, the rate penalty is fixed to $\varepsilon = 0.05$, and the channel gain $a_{12} \in (0,10)$. Figure 5-4 shows that the capacity keeps almost constant for the SNR range ($> 2$ dB). However, a capacity gap is observed for the range $a_{12} \in (1e-7,2)$. This gap becomes small with the decrease of $P_1$. This phenomenon is due to the nature of interference, i.e., both very large and very small interference show the identical impact on the system performance [Sato81].

5.5.3 Test Case 3

![Figure 5-5: Capacity of the secondary link with the localization information](image)

The objective of this test case is to see the capacity limit without the knowledge of $a_{21}$ but with the knowledge of $\delta_{21}^2$, which is set to $\delta_{21}^2 = 0.02$. Figure 5-5 shows the capacity results for two cases, i.e., $p_t = 0.1$ and $p_t = 0.01$. In contrast with Figure 5-4, the localization-assisted IACR shows more than 1 bit/Hz/sec loss in rate (see $p_t = 0.1$). Further reducing $p_t$ to 0.01 leads to more loss in transmission rate (more than 0.2 bit/Hz/sec).

5.6 Conclusion

In this chapter, we have investigated capacity theorems for the IACR system in two scenarios. One scenario was about the situation, where the secondary transmitter had the perfect channel side
information. The other was about the situation, where the secondary transmitter did not know the channel between the primary receiver and itself, but obtained the channel variance from localization systems. Numerical results have shown that the localization information could help the IACR system, but could not offer comparable performance with the case with perfect channel side information.

6 Conclusion

This document presents the intermediate version of location based cross-layer optimisation for PHY/MAC in OFDM based systems. The main contributions in this document include using positioning information to study:

- PHY/MAC optimizations, considered jointly with strategies for using multi-hop relays in a cooperative Ad-hoc networks (AAU);
- MTMR method, taking the advantage of the constellation of neighbouring base stations (BSs) serving the same area, namely their cell borders and the knowledge of the user terminal positions, to exploit cellular Alamouti diversity (CAD) and the macro diversity as a result of the broadcasted areas;
- Channel estimation for radio resource management, to maximize overall throughput in WiMAX, where this estimation is based on previous state of the channel and the positioning information (IT);
- In the Cognitive Radio perspective, the process of estimating channel between the secondary transmitter and the primary receiver interferes with the primary communication, making use of localization information to determine the spatial spectrum hole for frequency reuse (UniS);

In Chapter 2 we have outlined intended work regarding cross-layer optimization of transmission power and use of relaying transmissions. This work will be closely related to the activities in T3.3 and T3.4 and is performed during year 2 of WHERE.

In the MTMR study in the chapter 3, which exploits diversity both in macro diversity, the cell Cyclic Delay Diversity (C-CDD) is applied and Multiple transmission as cellular Alamouti diversity (CAT), showed that transition power saving is achieved. The throughput performance with halved transmit power is better than the performance of the reference system. Results show that for the adaptive transmit power scheme depending on the user’s position (the adaptive C-CDD) the received diversity and the resulting performance gain are increased in a wider area around the cell border. In contrast to the non-adaptive C-CDD with halved transmit powers at both BSs, the power adaptation guarantees the reception of the signal with maximum power throughout the whole cell.

In the chapter 4 a whole DRA for WiMAX system is described with all the details related to the Radio Resource Management. Is also demonstrated how the delay between the scheduling and transmission can affect the throughput, and a fast fading channel estimation method based of positioning is proposed. Although the whole methodology for this evaluation was described, the results concerning the system performance will be presented in the advanced version of cross-layer optimization.

Chapter 5 presented capacity theorems for the IACR system in two scenarios. One scenario was about the situation, where the secondary transmitter had the perfect channel side information. The other was about the situation, where the secondary transmitter did not know the channel between the primary receiver and itself, but obtained the channel variance from localization systems. Numerical results have shown that the localization information could help the IACR system, but could not offer comparable performance with the case with perfect channel side information.

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