



Deliverable D3.2

First performance results for multi-node/multi-antenna transmission technologies

Project Number:	ICT-317669
Project Name:	Mobile and wireless communications Enablers for the Twenty-twenty Information Society

Document Number:	ICT-317669-METIS/D3.2
Document Title:	First performance results for multi-node/multi-antenna transmission technologies
Editor(s):	R. Fantini (TI)
Author(s):	R. Fantini (TI), A. Santos (ALU), E. de Carvalho (AAU) and N. Rajatheva (UOULU) P. Popovski (AAU) P. Baracca, D. Aziz, J. Hoydis, F. Boccardi, (ALU) T. Svensson, J. Li, T. R. Lakshmana, Y. Sui (CTH) A. Benjebbour, S. Suyama (DOCOMO) R. Abrahamsson, G. Fodor (EAB) A. Jaziri, D.T. Phan Huy, H. Khanfir, R. Visoz, Y. Yuan, Y. Lejosne, Abdulaziz Mohamad, A. Saadani (FT) M. Kurras, L. Thiele (HHI) Y. Long, N. Vucic (HWDU) B. Slimane, H. Ghauch, M. Skoglund, S. M. Kim, M. Bengtsson (KTH) P. Jänis, T. Ihalainen (NOKIA) W. Zirwas (NSN) P. Sroka, K. Ratajczak, K. Bąkowski (PUT) K. Guo (RWTH) G. Dell'aera, B. Melis, M. Caretti (TI) C. Bockelmann, F. Lenkeit (UB) A. Tölli, K. S. Jayasinghe (UOULU) S. Roger, D. Calabuig, J. F. Monserrat (UPVLC) M. Sternad (UU)
Dissemination Level:	PU (indicate the dissemination level)
Contractual Date of Delivery:	30/04/2014
Status:	Final



Version:	1
File Name:	METIS_D_3.2_v1.docx

Revision History:

Revision	Date	Issued by	Description
1	April 30, 2014	METIS	D3.2 release v1

Abstract:

This deliverable describes the current results of the multi-node/multi-antenna technologies investigated within METIS and analyses the interactions within and outside Work Package 3. Furthermore, it identifies the most promising technologies based on the current state of obtained results. This document provides a brief overview of the results in its first part. The second part, namely the Appendix, further details the results, describes the simulation alignment efforts conducted in the Work Package and the interaction of the Test Cases. The results described here show that the investigations conducted in Work Package 3 are maturing resulting in valuable innovative solutions for future 5G systems.

Keywords:

Multi-antenna, Massive-MIMO, inter-node coordination, relay, multi-hop communication, wireless network coding, mm-waves



Executive summary

This document focuses on presenting the current results of the technologies investigated in Work Package 3 (WP3) and on providing guidance on the multi-node/multi-antenna transmission technologies for the METIS project. Additionally, it identifies the most promising approaches investigated in WP3 based on the current simulation results.

The structure of tasks, research clusters, and technology components follow D3.1 [METIS31], where WP3 is divided in three tasks: Multi-antenna/Massive-MIMO (T3.1), Advanced inter-node coordination (T3.2) and Multi-hop communications/wireless network coding (T3.3). Furthermore, each task is composed of research clusters.

This document is divided in two main parts. The first one is the main body, where the current results of each technology component are presented in a concise manner by visualization tables. Additionally, the first part of the document also identifies the most promising approaches of WP3 based on the current results and summarizes the interactions of WP3 with other Work Packages.

The second part of the document, the appendix, is of high importance for this document. The appendix shows the simulation alignment conducted in the tasks as well as the impact on the test cases of METIS. Additionally, it also details further the results of the technology components summarized in the main body of this document.

The most recent results in this document will show that WP3 is very well positioned, showing a good mix of medium and long term impact, and is providing valuable inputs for the development of 5G systems.

Task 3.1 has identified that Massive MIMO as in-band backhaul is a significant enabler of ultra dense networks and an essential feature for the goal of capacity increase in 5G systems. Another high potential approach that was identified was Massive MIMO for access.

Task 3.2 has identified two main approaches as very promising ones for 5G systems: firstly, the use of UEs with advanced capabilities alleviates the coordination complexity at the network side and reduces the feedback requirements. Secondly, the combination of Massive MIMO and CoMP solves issues of traditional interference coordination schemes, such as rank deficiency and limited indoor coverage.

Task 3.3 has identified in-band backhaul and access for its most promising technologies. There, technology components consider heterogeneous networks at lower frequencies (<10GHz) and also mesh networks at mm-waves for indoor scenarios.



Contents

1	Introduction	1
2	Task 3.1: Multi-antenna/Massive-MIMO	2
2.1	General overview	2
2.2	Research cluster 1: Effect of real world impairments and related enablers.....	2
2.2.1	Introduction	2
2.2.2	Overview of preliminary results	3
2.2.3	TeC complementarity analysis	10
2.3	Research Cluster 2: Further studies on Massive-MIMO precoding schemes under ideal assumptions	12
2.3.1	Introduction	12
2.3.2	Overview of preliminary results	14
2.3.3	TeC complementarity analysis	18
2.4	Most promising concepts from Task T3.1	18
2.5	Interactions between T3.1 and other METIS WPs	18
2.6	Conclusion	19
3	Task 3.2: Advanced inter-node coordination	20
3.1	General overview	20
3.2	Research Cluster 1: Further improvements to classical coordination techniques.....	20
3.2.1	Introduction	20
3.2.2	Overview of preliminary results	22
3.2.3	TeC complementarity analysis	25
3.3	Research Cluster 2: Studies on Interference Alignment	26
3.3.1	Introduction	26
3.3.2	Overview of preliminary results	28
3.3.3	TeC complementarity analysis	31
3.4	Research Cluster 3: Coordination with enhanced network and UE capabilities	31
3.4.1	Introduction	31
3.4.2	Overview of preliminary results	33
3.4.3	TeC complementarity analysis	41
3.5	Most promising concepts from Task T3.2	42
3.6	Interactions between T3.2 and other METIS WPs	43
3.7	Conclusion	43
4	Task 3.3: Multi-hop communications/wireless network coding	44
4.1	General overview	44
4.2	Research Cluster 1: Infrastructure-based relaying and wireless backhauling	44
4.2.1	Introduction	44
4.2.2	Overview of preliminary results	45
4.2.3	TeC complementarity analysis	51
4.3	Research Cluster 2: Infrastructure-less/infrastructure-assisted D2D and mobile relays	51
4.3.1	Introduction	51
4.3.2	Overview of preliminary results	53
4.3.3	TeC complementarity analysis	58
4.4	Most promising concepts from Task T3.3	58
4.5	Interactions between T3.3 and other METIS WPs	59
4.6	Conclusion	60
5	Conclusion and future work	61
6	References.....	62
7	Appendix A: Impact on Test Cases	64
8	Appendix B: Simulation Baselines	74
8.1	Simulation Baseline for Task 3.1	74
8.2	Simulation Baseline for Task 3.2	75
8.3	Simulation Baseline for Task 3.3	76



9 Appendix C: Preliminary Simulation Results..... 79

9.1 Preliminary Results for Task 3.1..... 79

9.1.1 T3.1 TeC.01 MIMO communications with large aperture massive array systems .
..... 79

9.1.2 T3.1 TeC.01b DFT based spatial multiplexing and maximum ratio transmission
for mm-wave large MIMO 80

9.1.3 T3.1 TeC.02 Coordinated resource and power allocation for pilot and data
signals in multicell SIMO systems 82

9.1.4 T3.1 TeC.04 Multi-cell MU-MIMO in real world scenarios – performance
evaluation of EVD-based channel covariance feedback and multi-path extraction in
massive MIMO systems 84

9.1.5 T3.1 TeC.05 Model Based Channel Prediction (MBCP) 86

9.1.6 T3.1 TeC.06 Adaptive large MISO downlink with predictor antenna array for very
fast moving vehicles 88

9.1.7 T3.1 TeC.07 Massive MIMO transmission using higher frequency bands based
on measured channels with CSI error and hardware impairments..... 91

9.1.8 T3.1 TeC.08 Massive MIMO and ultra dense networks 93

9.1.9 T3.1 TeC.09 EVD-based channel estimations in MU-Massive-MIMO systems. 95

9.1.10 T3.1 TeC.10 Decentralized coordinated transceiver design with large antenna
arrays 97

9.1.11 T3.1 TeC.11 Massive SDMA with a LSAS exploiting elevation and azimuth
beamforming 99

9.2 Preliminary Results for Task 3.2..... 101

9.2.1 T3.2 TeC.01 Multi-node resource allocation under imperfect feedback and
backhaul channels 101

9.2.2 T3.2 TeC.02 Exploiting temporal channel correlation to reduce feedback in
CoMP scheme..... 103

9.2.3 T3.2 TeC.02b DoF and net DoF of recent schemes for the MIMO IC and BC with
delayed CSIT and finite coherence time 105

9.2.4 T3.2 TeC.03 Distributed precoding in multi-cell multi-antenna systems with data
sharing 107

9.2.5 T3.2 TeC.04 Real world Interference Alignment..... 109

9.2.6 T3.2 TeC.05 Semi-distributed IA algorithm for MIMO-IC channel with power
control convergence speed up 111

9.2.7 T3.2 TeC.06 Distributed low-overhead schemes for MIMO Interference Channels
..... 114

9.2.8 T3.2 TeC.07 Dynamic clustering with multiple receive antennas in downlink
CoMP systems 116

9.2.9 T3.2 TeC.08 Non Orthogonal Multiple Access..... 118

9.2.10 T3.2 TeC.10 Distributed Joint-Transmission CoMP with enhanced multi-antenna
receive processing 121

9.2.11 T3.2 TeC.11 Decentralized interference aware scheduling 123

9.2.12 T3.2 TeC.12 Network-assisted interference suppressing/cancelling receivers and
ultra-dense networks 125

9.2.13 T3.2 TeC.13 Extension of IMF-A interference mitigation framework to small cell
scenarios and Massive-MIMO 127

9.2.14 T3.2 TeC.14 Joint dynamic clustering and coordinated scheduling for relaying
with Physical Layer Network Coding 129

9.2.15 T3.2 TeC.15 Adaptive and energy efficient dense small cells coordination 130

9.2.16 T3.2 TeC.16 Non-coherent communication in coordinated systems..... 132

9.3 Preliminary Results for Task 3.3..... 134

9.3.1 T3.3 TeC.01 Coordinated multi-flow transmission for wireless backhaul 134

9.3.2 T3.3 TeC.02 Interference aware routing and resource allocation in a millimetre-
wave Ultra Dense Network 136



9.3.3	T3.3 TeC.03 Virtual full-duplex buffer-aided relaying.....	137
9.3.4	T3.3 TeC.04 Distributed coding for the multiple access multiple relay channel.....	139
9.3.5	T3.3 TeC.05 Bi-directional relaying with non-orthogonal multiple access	141
9.3.6	T3.3 TeC.06 MIMO physical layer network coding based underlay D2D communication	143
9.3.7	T3.3 TeC.07 Cooperative D2D communications	145
9.3.8	T3.3 TeC.08 Open-loop techniques in a network with D2D relaying.....	147
9.3.9	T3.3 TeC.09 Uplink enhancement of vehicular users by using D2D communications	149
9.3.10	T3.3 TeC.10 Combining physical layer network coding and MIMO for TDD wireless systems with relaying	152



List of Tables

Table 2.1: T3.1 RC1 Technology Components.....	3
Table 2.2: T3.1 RC1 Overview of the TeC complementarity analysis	11
Table 2.3: T3.1 RC2 Technology Components.....	12
Table 2.4: T3.1 RC2 Overview of the TeC complementarity analysis	18
Table 3.1: T3.2 RC1 Technology Components.....	21
Table 3.2: T3.2 RC1 Overview of the TeC complementarity analysis	26
Table 3.3: T3.2 RC2 Technology Components.....	26
Table 3.4: T3.2 RC2 Overview of the TeC complementarity analysis	31
Table 3.5: T3.2 RC3 Technology Components.....	32
Table 3.6: T3.2 RC3 Overview of the TeC complementarity analysis	42
Table 3.7: Interactions between T3.2 and METIS WPs	43
Table 4.1: T3.3 RC1 Technology Components.....	45
Table 4.2: T3.3 RC1 Overview of the TeC complementarity analysis	51
Table 4.3: T3.3 RC2 Technology Components.....	52
Table 4.4: T3.3 RC2 Overview of the TeC complementarity analysis	58
Table 4.5: Interactions between T3.3 and METIS WPs	59
Table 8.1: T3.1 RC1 and RC2 alignment for link level studies	74
Table 8.2: T3.1 RC1 and RC2 common baseline for system-level assumptions	74
Table 8.3: T3.3 Exemplary simulation assumptions.....	77
Table 9.1: DFT-SM-MRT performance at $m = 40$	80
Table 9.2: Simulation parameters.....	91
Table 9.3: Performance Gain for different numbers of subbands.....	119
Table 9.4: Simulation Parameters	149



List of Abbreviations, Acronyms, and Definitions

AgN	Aggregation Node
AN	Access Node
AWGN	Additive White Gaussian Noise
BC	Broadcast Channel
BCH	Broadcast Transport Channel
BER	Bit Error Rate
BF	Beamforming
BLER	Block Error Rate
BS	Base Station
BSOS	Border Switch Off Scheme
BVDM	Building Vector Data Map
CC	Centralized Controller
CCI	Co-Channel Interference
CD2DC	Cooperative D2D communication
CDMA	Code Division Multiple Access
CoMP	Coordinated Multi Point
CSG	Closed Subscriber Group
CSI	Channel State Information
CSIT	Channel State Information at the Transmitter
CU	Central Unit
DL	Downlink
D2D	Device-to-Device
DCMR	Dynamic Clustering with Multi-antenna Receivers
DCSIT	Delayed Channel State Information at the Transmitter
DFT	Discrete Fourier Transform
DIAS	Decentralized Interference Aware Scheduling
DoF	Degree of Freedom
DPC	Dirty Paper Coding
DPS	Dynamic Point Selection
eICIC	enhanced Inter Cell Interference Cancellation
eNB	evolved Node B
E2E	End-to-End
EPA	Extended Pedestrian A
ETU	Extended Typical Urban
EVA	Extended Vehicular A
EVD	EigenValue Decomposition
FCFB	Foresighted Channel Feedback
FDD	Frequency Division Duplex
FER	Frame Error Rate
HD	Half Duplex
HeNB	Home evolved Node B
HT	Horizontal Topics
HTD	Horizontal Topic Driver
IBC	Interfering Broadcast Channel
IA	Interference Alignment
IAR	Interference Aware Routing
IC	Interference Channel
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Cancellation
IDMA	Interleave Division Multiple Access

IMAC	Interfering Multiple Access Channel
IMF-A	Interference Management Framework from Artist4G
IRI	Inter-Relay Interference
ISD	Inter Site Distance
JP	Joint Processing
JT	Joint Transmission
KPI	Key Performance Indicator
LAN	Local Area Network
LOS	Line Of Sight
LSAS	Large Scale Antenna System
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
M-MIMO	Massive MIMO
M2M	Machine to Machine
MAC	Multiple Access Channel
MAMRC	Multiple Access Multiple Relay Channel
MBCP	Model Based Channel Prediction
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMC	Massive Machine Communication
MMRS	Max-Max Relay Selection
MMSE	Minimum Mean Square Error
MMW	Millimetre Waves
MRN	Moving Relay Node
MRT	Maximum Ratio Transmission
MS	Mobile Station
MSE	Mean Square Error
MUE	Macro served User Equipment
MUI	Multi-user Interference
MUICIA	Multi-user Inter Cell Interference Alignment
MU-MIMO	Multi-user MIMO
N/A	Not Applicable
NA	Network Assisted
NA IS/IC	Network Assisted Interference Suppression / Interference Cancellation
NC	Network Coding
NLOS	Non Line of Sight
NMSE	Normalized Mean Square Error
NOMA	Non Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
PC	Power Control
PF	Proportional Fair
PHY	Physical layer
PI	Polynomial Interpolation
PLNC	Physical Layer Network coding
PRBS	Physical Resource Blocks
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RA	Resource Allocation
RAN	Radio Access Network



RAT	Radio Access Technology
RC	Research Cluster
RF	Radio Frequency
RN	Relay Node
RRM	Radio Resource Management
RS	Relay Station
RSOS	Random Switch Off Scheme
RX	Receiver
SC	Small Cell
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCM	Spatial Channel Model
SDF	Selective Decode and Forward
SDMA	Spatial Division Multiple Access
SFD	Space Full-Duplex
SIMO	Single Input Multiple Output
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input Single Output
SM	Spatial Multiplexing
SRTA	Separate Receive and Training Antenna
SUE	Small cell User Equipment
SVD	Singular Value Decomposition
T	Task
TC	Test Case

TD	Transceiver Design
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TeC	Technology Component
TP	Transmission Point
TRX	Transceiver
TX	Transmitter
UDN	Ultra Dense Network
UE	User Equipment
UHF	Ultra High Frequency
UL	Uplink
UMTS	Universal Mobile Telecommunications System
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VFD-BR	Virtual Full Duplex Buffer-aided Relaying
VUE	Vehicular UE
WA	Wide Area
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WNC	Wireless Network Coding
WP	Work Package
ZF	Zero Forcing



1 Introduction

This deliverable has two main goals:

- 1) First, to describe the first performance evaluation of the Technology Components (TeCs) in Work Package 3 (WP3);
- 2) Secondly, to provide guidance on the identification of most promising multi-node/multi-antenna transmission technologies for the METIS project.

In order to fulfill Goal 1, an update of the TeCs under investigation in WP3 is presented. The results are summarized with the use of visualization tables, so that one can easily have an overview of them. The TeCs are grouped as in D3.1, where each of the tasks is divided in Research Clusters (RCs) grouping TeCs with similar focus. Further explanation about the structure and division of RCs and TeCs can be found in D3.1. The tables consist of an initial explanation of the main idea with a basic illustration of the concept. The summary of the results is then contained in field “Key Performance Indicators (KPIs) considered and expected gain”. Additionally, information about the simulation approach is also depicted in the table. More detailed explanation of the current results can be found in Appendix C.

Notice that the results presented here are partially based on the simulation alignment effort that was conducted in each task, in order to identify a common baseline with specific simulation parameters and scenarios. The scenarios and parameters of this simulation alignment are described in Appendix B of this document. This alignment effort has been done in order to create the right conditions for a uniform assessment of WP3 technologies and to better infer the impact of them in a close to realistic scenario. Additionally, this supports the identification of the most promising solutions based on the current results. Another aspect here is the TeC complementary analysis, where the interactions and relations among TeCs inside a research cluster are depicted. This facilitates the cooperation among partners working on complementary TeCs as well as the conception of the system analysis performed in WP6.

This simulation alignment is connected to Goal 2 of this deliverable. Here, the impact of the TeCs on the Test Cases (TCs) of METIS as well as the interactions with other WPs is described. Finally, each task of WP3 highlights the most promising approaches based on the current results. Those most promising approaches are identified based on the current simulation results. An update of them will be provided later in D3.3, where the final results will be available. Therefore, it is to expect that technologies that are not yet highlighted here will be identified in the near future as a consequence of the further investigations.

This document is organized as follows: Sections 2, 3 and 4 describe the results of Tasks 3.1, 3.2 and 3.3, respectively. Each of those sections is further divided by RCs. Each RC subsection contains the tables with the overview of the results and the TeC complementary analysis. Finally, each section regarding a specific task describes the most promising technologies and their requirements and interactions with other WPs.

Finally, the general conclusions and further work are elaborated upon. Additionally, this deliverable comes with three appendices, where Appendix A describes the impact of each TeC on the TCs, Appendix B introduces the simulation alignment for each RC and Appendix C contains more comprehensively detailed results of each TeC.



2 Task 3.1: Multi-antenna/Massive-MIMO

2.1 General overview

Task 3.1 considers further development of multi-antenna/massive Multiple-Input Multiple-Output (MIMO) techniques as initially discussed in D3.1 [METIS31]. Work carried out up to now by different partners indicates specific directions where some results have been obtained and published. In this task the research is conducted in two RCs. In RC1, the thrust is to look at more realistic scenarios where impairments such as channel errors/hardware imperfections, mobility, high frequencies up to mm wave region, and large aperture systems where near field modelling is of importance, are given due consideration. Attention is also focused on pilot and data power allocation as this has implications to pilot contamination. At the same time as the massive MIMO concept is still relatively new, more fundamental work is carried out in RC2 to obtain a clearer picture in terms of multi-cellular structures, heterogeneous networks and to investigate transceiver processing performance limits, taking also into account more detailed channel models and access schemes. The most common assumption in both the clusters is Time-Division Duplexing (TDD). A complementarity analysis is carried out for TeCs in each RC which shows similarities and differences.

As more results are now available it would also be useful to see how these different methods contribute, at a system level, to some test cases as identified by D1.1 [METIS11]. An important consideration therefore is to be able to integrate and compare approaches and results from different partners into a common simulation model for each RC. One major objective of this deliverable is to identify the simulation environment-parameters so that further results can be obtained with respect to these from each of the partners, and also to identify key technologies which could be utilized to realize test cases as needed to meet overall objectives in the project. Thus various TeCs considered in this task are assessed with respect to the METIS TC 2 “Dense urban information society”.

2.2 Research cluster 1: Effect of real world impairments and related enablers

2.2.1 Introduction

In this RC, the objective is to look at more realistic scenarios with impairments. TDD is considered as the duplexing scheme. The studies concentrate on factors such as channel errors/hardware imperfections, mobility, high frequencies up to mm-wave region, and large aperture systems where near field modelling is of importance. The particular topics under consideration in this RC are:

- Reduced complexity processing for mm-wave large MIMO.
- Model based channel prediction through an accurate building vector data map.
- Beamforming for high-mobility scenarios.
- Quasi-mm-wave schemes with hardware impairments.

All the TeCs are compared with respect to the METIS TC 2 “Dense urban information society” from [METIS11]. The main requirements of this TC are a traffic volume density of about 700 Gbps/km² and a user/device density up to 200 000 per km² combined with availability and reliability of 95% in space and frequency. These challenges are addressed by the benefits achieved with the provided TeC 1 to 7.

A more detailed overview of the TeCs related to RC1 is given in the next section. Table 2.1 provides a summary of the main TeC ideas.



Table 2.1: T3.1 RC1 Technology Components

TeC #	Short Title	Short description
TeC 1	Large aperture massive MIMO	Development of low-complexity and energy-efficient multi-antenna transceiver techniques for Large Aperture Massive Array Systems
TeC 1b	DFT-SM-MRT	Discrete Fourier Transform (DFT) based spatial multiplexing (SM) and maximum ratio transmission (MRT) for mm-wave large MIMO
TeC 2	Coordinated pilot and data Resource Allocation (RA) in multicell massive SIMO System	Coordination of resources used for pilot and data transmission in a multi-cell massive Single Input Multiple Output (SIMO) system. Goal of the coordination is to mitigate pilot contamination and reduce inter-cell interference.
TeC 4	EVD-based blind channel covariance estimation	Analyse the performance of eigenvalue decomposition (EVD) based blind channel covariance estimation methods and compare them with ideal multi-path extraction, also to investigate the feasibility of massive MIMO systems with non-reciprocal duplex channels.
TeC 5	Model Based Channel Prediction (MBCP)	Exploit detailed knowledge of the eNB environment in form of an accurate building vector data map (BVDM) for channel prediction. UEs feedback their relative location on the BVDM and the eNB reconstructs the wideband radio channel based on this information
TeC 6	Predictor antenna array for fast moving vehicles	Adaptive Large MISO Downlink with Predictor Antenna Array for very fast moving vehicles
TeC 7	M-MIMO-MMW	Massive MIMO (M-MIMO) transmission using higher frequency bands based on measured channels with CSI error and hardware impairments

2.2.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.1 RC 1, collected in a series of tables that highlight expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C section 9.1.

Gains in the tables are specified as improvements of certain KPI, referring to those defined in the METIS project [METIS11] whenever they are relevant. The followed approach for the evaluation could be either analytical or simulation based [METIS61]; and for TeCs evaluated through simulations, also the simulation type and dynamic class are specified in the table, according to the taxonomy given in [ARTIST51]. In particular, the simulation type could be:

- **System level:** used for evaluation of protocol layers 1 and 2. Link level performance and effects of higher layers are simplified or fed from evaluations of other types.
- **Link level:** used for detailed evaluation of a point-to-point connection.
- **Multi link level:** used for detailed evaluation of a point-to-multi-point connection (or vice versa). Equivalent of the link level evaluation but for multi-link techniques.

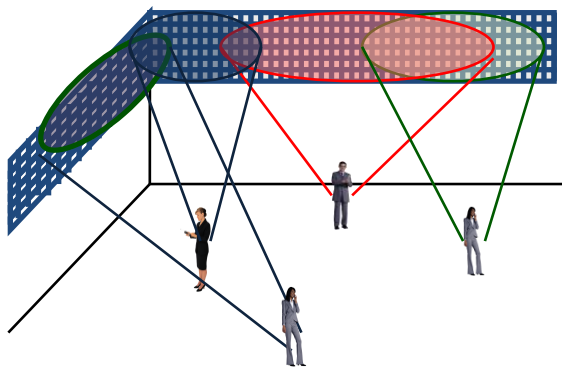
For the dynamic class we consider:

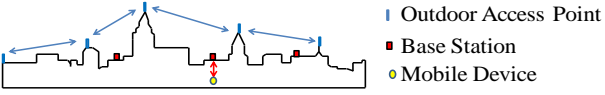

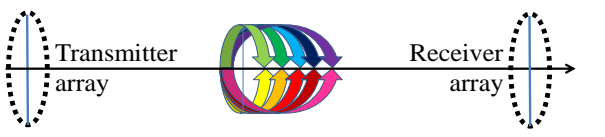
- **Static model:** number and locations of the active users are fixed. Fast fading effects may be included.

- **Semi-static model:** positions of active users are modeled by a random distribution, but the positions of active users are fixed over a simulation run. Multiple simulation runs are carried out. Fast fading effects may be included.
- **Semi-dynamic model:** users arrive at random times and locations and require some random services. Each user remains in the same location. Fast fading effects may be included.
- **Dynamic model:** users arrive at random times and locations and require some random services. Users may move during their activity.

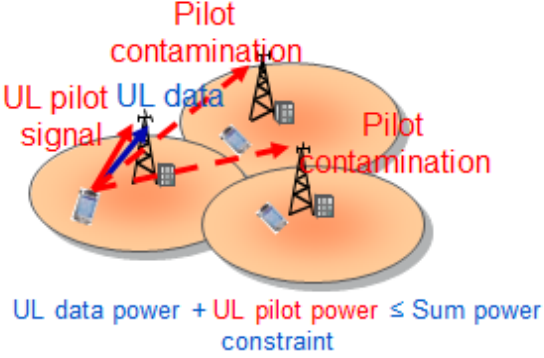
The considered system model could be either the baseline ('RC baseline') defined for the specific RC in Task 3.1 (see Appendix B section 8.1), or a different one ('Other'). Each table specifies the followed approach and, when it is reasonable, the level of deviation compared to the baseline; if needed, more information is reported in Appendix C.

In the end, for each TeC a legacy solution is identified as a reference for the evaluation of the expected gains. LTE Rel'11 is assumed whenever it is relevant, but different and specific legacies are also possible; also in this case more details can be found in Appendix C, along with the available simulation results.

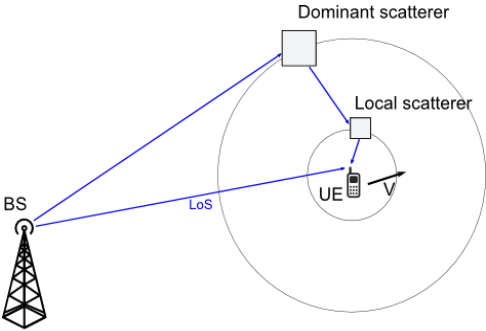
T3.1 TeC.01 - MIMO communications with large aperture massive array systems	
	<p style="text-align: center;">Main Idea</p> <p>The main idea is to deploy massive arrays of large aperture to serve as access points in infrastructures such as airport halls, shopping malls, stadium, concert stages, etc. In such a hot spot, communication happens in the near-field where the phase and amplitude of the channel varies across the array. The general objective is the development of low-complexity and energy-efficient multi-antenna transceiver techniques in a multi-user communication framework where a 2D or 3D large array serves multiple users simultaneously.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Spectral Efficiency: gains to be evaluated • Energy Efficiency: gains to be evaluated
Performance Evaluation Approach	Analytical and Simulation-based.
Simulation Type	Not Applicable
Dynamic Class	Not Applicable
System Model Considered	Other
Deviation compared to RC Baseline	Not Applicable
Considered Legacy Solution	Not Applicable

T3.1 TeC.01b - DFT based spatial multiplexing and maximum ratio transmission for mm-wave large MIMO	
 <p>mm-wave for both backhaul and direct links</p>  <p>With linear arrays, data streams are mapped onto angles of arrivals.</p>  <p>With circular arrays data streams are mapped onto vortices of various orbital angular momentums.</p>	<p style="text-align: center;">Main Idea</p> <p>According to the antenna spacing and transmitter-receiver distance, the large MIMO channel in mm-wave communications is likely to be ill-conditioned. In such conditions, highly complex schemes such as the singular value decomposition (SVD) are necessary. We propose a new low complexity system called discrete Fourier transform based spatial multiplexing (DFT-SM) with maximum ratio transmission (DFT-SM-MRT). When the DFT-SM scheme alone is used, the data streams are either mapped onto different angles of departures in the case of aligned linear arrays, or mapped onto different orbital angular momentums in the case of aligned circular arrays. Maximum ratio transmission pre-equalizes the channel and compensates for arrays misalignments.</p>
KPIs considered and Expected gain	Spectral Efficiency: x166 [bits/s/Hz]. Complexity reduction with N antennas $\approx O(N^2)$: x $3 \cdot 10^5$
Performance Evaluation Approach	Simulation based
Simulation Type	Link level simulation
Dynamic Class	Static model
System Model Considered	Other
Deviation compared to RC Baseline	Not Applicable.
Considered Legacy Solution	mm-wave single input single output (SISO) system for spectral efficiency, SVD scheme for complexity.

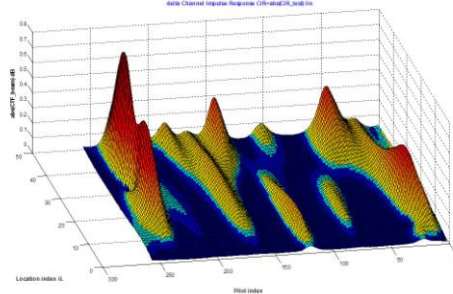
T3.1 TeC.02 - Coordinated resource and power allocation for pilot and data signals in multicell massive SIMO systems

 <p>UL data power + UL pilot power ≤ Sum power constraint</p> <p>Idea: Low rate coordination of pilot and data resource and power allocation</p>	<p>Main Idea</p> <p>In multi-cell massive MIMO systems, pilot contamination depends on the resources and transmit-power levels used for the pilot signals. On the other hand, there is an inherent trade-off between the resources used for pilot and data signals. The main idea is to use low rate multi-cell coordination to find the optimal multi-cell resource allocation for pilot and data signals under a sum power constraint. Ideally, this method finds the right balance between pilot and data power allocation taking into account pilot contamination and inter-cell interference.</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • Energy efficiency, 5 – 30 % [bps/W] • Data rates, 5 – 30 % [bps] <p>Both the energy efficiency and the data rates can be improved by requiring less sum pilot+data power for a prescribed mean square error (MSE) of the equalized data symbols or decreasing the MSE with a predefined pilot+data power budget.</p>
<p>Performance Evaluation Approach</p>	<p>Analytical and sSimulation-based (hybrid) approach. Analytical approach is used to determine the MSE for an arbitrary pilot+data power setting as a function of the number of base station antennas without pilot contamination. Simulation and analysis are used jointly in the presence of pilot contamination.</p>
<p>Simulation Type</p>	<p>System level evaluation for the simulation-based part.</p>
<p>Dynamic Class</p>	<p>Semi-static model.</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Not Applicable. The system level evaluation uses Gaussian channel model and the positions of active users are drawn from a surface uniform distribution.</p>
<p>Considered Legacy Solution</p>	<p>System without multi-cell coordination and without pilot-data power balancing.</p>

T3.1 TeC.04 – Multi-cell MU-MIMO in real world scenarios – performance evaluation of EVD-based channel covariance feedback and multi-path extraction in massive MIMO systems

 <p>In the downlink, fast fading components can be estimated at UE, fed back to BS to improve CSIT.</p>	<p>Main Idea</p> <p>In multi-path massive MIMO systems, one method to obtain downlink channel knowledge is by covariance feedback with blind estimation in reciprocal duplex channels, e.g., time-division duplex (TDD). In case of non-reciprocal frequency-division duplex (FDD) mode, the uplink channel covariance can be transformed to downlink. However, the performance of such a transformation is limited due to unknown random phase components of each path. The main idea is to estimate the phase components of the strongest paths at user equipment (UE) and feed them back to the serving base station to further improve the estimation accuracy.</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> The performance gain is still to be evaluated <p>The downlink user throughput can be improved by more accurate estimation of the channel, which is reflected via beamforming gain with large transmit antenna arrays in the downlink.</p>
<p>Performance Evaluation Approach</p>	<p>Simulation-based approach. Simulation uses covariance feedback estimation in both reciprocal and non-reciprocal channels, as well as ideal estimation of 'N' strongest paths, where 'N' is a design parameter.</p>
<p>Simulation Type</p>	<p>System level evaluation</p>
<p>Dynamic Class</p>	<p>Semi-static model.</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Not Applicable. The system level evaluation uses Gaussian channel model and the positions of active users are drawn from a surface uniform distribution.</p>
<p>Considered Legacy Solution</p>	<p>Channel covariance feedback</p>

T3.1 TeC.05 – Model based channel prediction



Typical evolution of channel prediction errors (z-axis) over time (y-axis) for different PRBs (x-axis) for parameter estimation based on 'model based channel prediction'

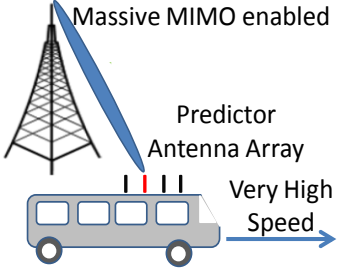
Main Idea

It is a – partly - theoretical study on limitations of model based channel prediction (MBCP). It investigates novel algorithms for extraction of as much as possible of relevant information out of coarse building vector data maps (BVDM) for channel prediction. MBCP is thereby seen as one of the most important enablers for future advanced radio algorithms like Joint Transmission CoMP JT CoMP or Massive-MIMO.

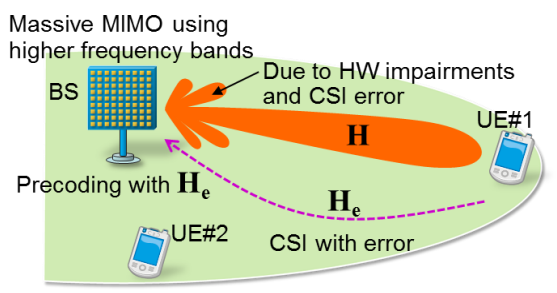
Compared to D3.1 a low rate low latency feedback channel has been added to keep track of strong prediction errors on a limited set of the physical resource blocks (PRBs).

<p>KPIs considered and Expected gain</p>	<p>Prediction Horizon: Expected Gain: from 0.1 - 0.3 λ for Kalman filtering to 0.5 - 1 λ for MBCP</p> <p>Robust channel prediction: Normalized Mean Square Error (NMSE) of precoding error <-15dB for > 90% of the resources (PRBs)</p> <p>System level gains are for the interference management framework from Artist4G (IMF-A) plus its extensions relying on model based channel prediction</p> <p>Spectral efficiency: Expected Gain > 100%</p> <p>Throughput: Expected Gain >100%</p>
<p>Performance Evaluation Approach</p>	<p>Simulations / partly Analytical</p>
<p>Simulation Type</p>	<p>Link level simulations for single and multiple links</p>
<p>Dynamic Class</p>	<p>Not Applicable (Dynamic model)</p>
<p>System Model Considered</p>	<p>Building vector data map for Munich NSN campus scenario 3GPP case 1, 2.6GHz, only outdoor users</p>
<p>Deviation compared to RC Baseline</p>	<p>Some:</p> <ul style="list-style-type: none"> • Model of environment: wide area outdoor • Spectrum Assumptions: ~cm wave range – 2.6GHz • Propagation model: 3GPP case 1 • Deployment model: Wide Area network only and in combination with small cells • User/Device Distribution: uniform • Traffic model: full buffer
<p>Considered Legacy Solution</p>	<p>LTE Release 11 as baseline assumption with extensions for the reporting of channel state information (CSI)</p>

T3.1 TeC.06 - Adaptive large MISO downlink with predictor antenna array for very fast moving vehicles

 <p>Vehicle with very high speed served by a massive-MIMO enabled BS using very narrow beams. The vehicle is equipped with a predictor antenna array.</p>	<p style="text-align: center;">Main Idea</p> <p>A new scheme called “Polynomial Interpolation” (PI) is proposed specifically for large MISO downlink beamforming in TDD. The objective is to provide a highly efficient wireless backhaul, in terms of energy consumption, for fast moving vehicular relays. Beamforming miss-pointing occurs at high speed, due to outdated channel state information at the BS. An array of aligned predictor antennas, placed upon the roof of the vehicle periodically sends pilots to the BS, to provide a very dense pattern of channel measurements in space. The BS interpolates the measurements to predict the channel between the BS and the receive antenna, accurately. The Polynomial Interpolation scheme is compared to several less complex prediction techniques derived from the Separate Receive and Training Antenna (SRTA) scheme [PHH13], namely a Random Switch Off Scheme (RSOS), the Border Switch Off Scheme (BSOS) and a Reference System (RS). See Appendix C section 9.1.6 for further details.</p>
<p>KPIs considered and Expected gain</p>	<p>TX Energy Saving: x1 to x30 BLER: x1 to x100</p>
<p>Performance Evaluation Approach</p>	<p>Simulation based</p>
<p>Simulation Type</p>	<p>Link level simulation</p>
<p>Dynamic Class</p>	<p>Static model</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Not Applicable.</p>
<p>Considered Legacy Solution</p>	<p>System with outdated channel prediction</p>

T3.1 TeC.07 - Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments

 <p style="text-align: center;">System Model</p> <p>Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments</p>	<p style="text-align: center;">Main Idea</p> <p>Performance evaluation of Massive-MIMO transmission using higher frequency bands based on measured channels is performed by computer simulations, and requirements of both CSI error and hardware impairments are clarified. Computer simulations in Massive-MIMO eigenmode transmission are conducted using appropriate channel models exploiting CSI from Massive-MIMO channel sounder measurements in field experiments. In order to clarify the requirements, the influences of the CSI error and the hardware impairments on the throughput performance are evaluated. From these investigations, novel precoding and compensation methods will be proposed so as to satisfy the requirements for Massive-MIMO using higher frequency bands.</p>
---	--

KPIs considered and Expected gain	Supported traffic value density and experienced user throughput: Average SNR to achieve 20 Gbps throughput can be reduced by 17 dB at same transmitter power.
Performance Evaluation Approach	Simulation-based
Simulation Type	Link level simulation for single link
Dynamic Class	Static model
System Model Considered	Other
Deviation compared to RC Baseline	Not Applicable.
Considered Legacy Solution	System employing MIMO-OFDM without beamforming

2.2.3 TeC complementarity analysis

In order to identify interactions and relations among TeCs inside the RC this section presents a complementarity analysis between the innovations that have been described so far. Complementarity is defined as follows: TeCx complements TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy. Note that in general complementarity is not symmetric as TeCy does not necessarily enhance the performance of TeCx. Given this definition, Table 2.2 gives an overview of the complementary analysis performed for Research Cluster 1 innovations. In particular, TeC1 studies near field modelling and very large antenna arrays which therefore can be complementary to all other TeCs. TeC 1b considers a backhaul solution with symmetric massive MIMO and as such is not complementary to other TeCs. TeC2 investigates pilot and data power considerations, and hence, has complementarity to all TeCs. TeC4 looks into real world scenarios with channel covariance feedback and multipath extraction and hence is complementary to TeC5 which considers model based channel prediction. TeC 5 is complementary to mobility predictor



antennas discussed in TeC6. TeC7 goes into measured channels and hardware errors in quasi-mm wave region and is complementary to TeC1b which considers mm waves.

Table 2.2: T3.1 RC1 Overview of the TeC complementarity analysis

TeCx Comple ments TeCy	TeC 1 Large Aperture Massive MIMO	TeC 1b DFT- SM- MRT	TeC 2 Coordinated Pilot and Data RA	TeC 4 EVD-Based blind Channel Covariance estimation	TeC 5 Model Based Channel Prediction	TeC 6 Predictor Antenna Array	TeC 7 M-MIMO- MMW
TeC 1	-	Yes	Yes	Yes	Yes	Yes	Yes
TeC 1b	No	-	No	No	No	No	No
TeC 2	Yes	Yes	-	Yes	Yes	Yes	Yes
TeC 4	No	No	No	-	Yes	No	Yes
TeC 5	No	No	No	No	-	Yes	No
TeC 6	No	No	No	No	No	-	No
TeC 7	No	Yes	No	No	No	No	-

2.3 Research Cluster 2: Further studies on Massive-MIMO precoding schemes under ideal assumptions

2.3.1 Introduction

This RC is focused on further study of the theoretical foundations of large scale antenna systems (LSASs) and their application in cellular systems. The common assumption in the different contributions is the use of TDD as duplexing scheme. The studies herein target low-complexity precoding/beamforming solutions, interference rejection techniques, and asymptotic analysis for both uplink and downlink.

Some of the main challenges evoked by the large number of antennas at the macro BS and addressed in this RC are:

- Due to the high beamforming gain, integration into a cellular system by coordination with neighbor cells or small cells is necessary.
- Using straightforward extensions of MIMO algorithms, the complexity of transceiver signal processing is increased (sometimes exponentially) along with the number of transmit antennas. Therefore, the complexity of transceiver algorithms has to be reduced, e.g. by utilizing tools like random matrix theory.
- Obtaining reliable CSIT for transmit precoding/beamforming is still an open challenge. Therefore, algorithms have to be robust and CSI errors are considered as in RC1.
- Exploiting the high beamforming gain offered by LSASs, the energy and spectral efficiency has to be increased compared to current systems by reducing power consumption while still achieving the same performance or by increasing the performance while maintaining the same power consumption.

Throughout this RC all the TeCs are considered with respect to the METIS TC 2 “Dense urban information society” from [METIS11]. The main requirements of this TC are a traffic volume density of about 700 Gbps/km² and a user/device density up to 200 000 per km² combined with availability and reliability of 95% in space and time. These challenges are addressed by the benefits achieved with the provided TeC 8-12 briefly summarized in the following:

- TeC 8: Increase of area spectral efficiency in downlink and uplink by integration of LSASs and a dense layer of small cells in a TDD network architecture.
- TeC 9: Increase of user throughput and reduction of error rates in uplink with advanced transmit and receive processing in a multi-cell multi-user system with LSASs.
- TeC 10: Simplification of transceiver processing and reduction of transmit power in downlink by coordination between macro LSASs utilizing random matrix theory.
- TeC 11: Increase of spectral efficiency in downlink with massive spatial division multiple access (SDMA) and exploitation of azimuth and elevation beamforming with a large rectangular antenna array in a multi-cell multi-user system.

A more detailed overview of the TeCs related to RC 2 is given in the next section. Table 2.3 provides a summary of the main TeC ideas.

Table 2.3: T3.1 RC2 Technology Components

TeC #	Short Title	Short description
TeC 8	Massive MIMO and ultra dense networks	Study of a TDD based network architecture with the aim of integrating a massive MIMO macro network with a dense layer of small cells (SCs).

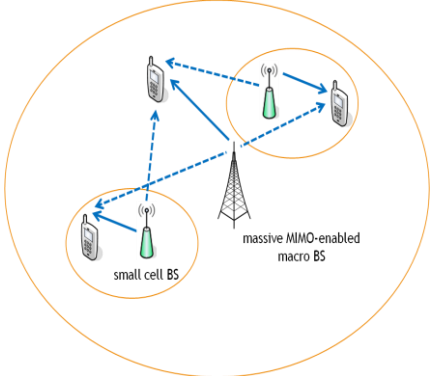


TeC #	Short Title	Short description
TeC 9	Eigenvalue decomposition (EVD) based channel estimation for MU-MIMO	Analytical and simulation based study on the use of an improved EVD-based channel estimation (widely linear algorithm) in multi-cell MU-Massive-MIMO systems.
TeC 10	Decentralized Transceiver design	To obtain simplified transceiver processing methods based on random matrix theory
TeC 11	Massive SDMA with a LSAS	A LSAS is used to apply massive SDMA exploiting elevation and azimuth beamforming. Instead of increasing the SINR of several users the beamforming gain is used to serve as many users as antennas available in the spatial domain.

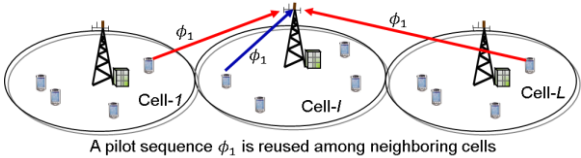
2.3.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.1 RC2, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C section 9.1.

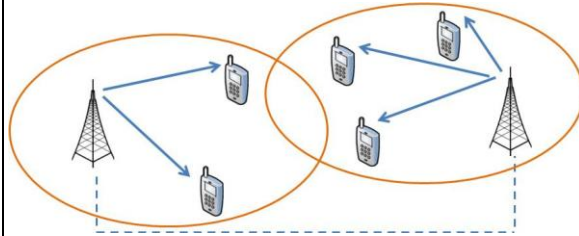
The structure and meaning of the different fields in the following tables have been described in section 2.2.2.

T3.1 TeC.08 - Massive MIMO and ultra-dense networks	
 <p>A network where a macro tier is augmented with low range small cells (SCs). Each macro BS employs multiple antennas to serve its associated single-antenna MUEs (Macro served UE). Each SC is equipped with multiple antennas and devotes its available resources to its pre-scheduled small-cell user equipment (SUE).</p>	<p style="text-align: center;">Main Idea</p> <p>We assume that transmissions across the tiers are perfectly synchronized. Both tiers share the available bandwidth with universal frequency reuse. All transmissions are assumed to take place over flat fading channels. The main idea is to exploit channel reciprocity not only for estimation of large-dimensional channels at the BSs but also for interference aware precoding with the goal of reducing intra- and inter-tier interference.</p> <p>The proposed scheme relies only on locally available information and does not require any data exchange between the nodes. It is hence fully distributed and scalable.</p>
KPIs considered and Expected gain	<p>Area spectral efficiency (SC, Uplink): average gain of 100%</p> <p>Area spectral efficiency (SC, Downlink): average gain of 50%</p> <p>Area spectral efficiency (macro, Uplink): average gain of 200%</p> <p>Area spectral efficiency (macro, Downlink): average gain of 150%</p>
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other
Deviation compared to RC Baseline	<p>Significant:</p> <ul style="list-style-type: none"> • Model of environment: Urban Macro Area • Spectrum Assumptions: 2.6 GHz • Propagation model: Simplified 3GPP Model [3GPP12-36828, Tab 6.4-1] • Deployment model: Square Grid • User/Device Distribution: Hotspot distribution • Traffic model: Full Buffer
Considered Legacy Solution	Adapted LTE Release 11

T3.1 TeC.09 - Eigenvalue decomposition (EVD) based channel estimation for MU-MIMO

 <p>A pilot sequence ϕ_1 is reused among neighboring cells</p>	<p>Main Idea</p> <p>The channel between a given user and its serving BS tends to become orthogonal to the channel of a randomly selected intra-/inter-cell interfering user as the number of BS antennas goes to infinity, assuming i.i.d. fast-fading channel with slow-fading known a priori. The channel vector is then the eigenvector of covariance matrix of RX data vector subject to a multiplicative (scalar/sign) ambiguity. We propose an improved EVD-based channel estimation, i.e. widely linear (WL) algorithm [AP12], in multi-cell MU-Massive-MIMO systems. By using both the received signal and its complex conjugate, the WL scheme reformulates the channel vectors into their real representations which are more pairwise orthogonal and reduces the phase ambiguity problem that is inherent from conventional subspace-based estimations to a sign ambiguity.</p>
<p>KPIs considered and Expected gain</p>	<p>User throughput: 2 times compared with [NL12] Symbol Error rate: 2 times improved compared with [NL12] MSE of channel estimate (not defined in [METIS11]) reduced to less than 50%.</p>
<p>Performance Evaluation Approach</p>	<p>Analytical and Simulation-based</p>
<p>Simulation Type</p>	<p>Simplified system level evaluation</p>
<p>Dynamic Class</p>	<p>Static model</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Multi-cell MU-Massive-MIMO system of L=3 cells and K=3 users in each cell</p>
<p>Considered Legacy Solution</p>	<p>[NL12]</p>

T3.1 TeC.10 - Decentralized coordinated transceiver design with large antenna arrays

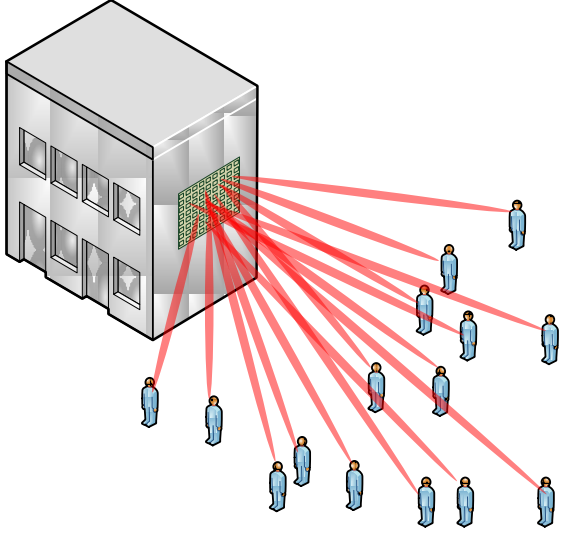


Each BS has a much larger number of antennas compared to those at user terminals. A decentralized beamforming algorithm is considered with some backhaul signaling among BSs.

Main Idea

MIMO interfering broadcast channel (IBC) and interfering multiple access channel (IMAC) are considered. Each BS serves its own set of user terminals and co-channel transmissions from each BS cause interference to the user terminals of other cells. Inter-cell interference (ICI) is a key parameter in the design of distributed beamforming algorithm as it couples the sub-problems at base stations. In this work, a large dimension approximation for the optimal ICI is considered. According to this approximation an algorithm is proposed for decoupling the sub-problems at base stations which results in a significant reduction in backhaul information exchange rate and processing load. This algorithm guarantees the target SINRs without any major loss of performance as compared to the optimal centralized design as the dimensions of the system grow large.

KPIs considered and Expected gain	Transmit power reduction to be evaluated Reduced signalling between network nodes (backhaul traffic)
Performance Evaluation Approach	Analytical and Simulation-based
Simulation Type	Link level, Multi-link level
Dynamic Class	Static model
System Model Considered	Multi-cell, multiple users with interferences considered in frequency flat fading.
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> • Model of environment: N/A (i.i.d. Rayleigh fading) • Spectrum Assumptions: Frequency agnostic • Propagation model: N/A (i.i.d. Rayleigh fading) • Deployment model: 7 cell wrap around • User/Device Distribution: 28 users dropped to random locations in cells • Traffic model: No traffic model
Considered Legacy Solution	Relevant works from the literature for the considered case [TPK11] [LHDA10] [DY10] [WCMD12]. LTE Rel. 12 baseline considered in the future

T3.1 TeC.11 – Massive SDMA with a LSAS exploiting elevation and azimuth beamforming	
 <p>A rectangular uniform antenna array serves a lot of users with spatial division multiple access.</p>	<p style="text-align: center;">Main Idea</p> <p>Given a TDD system where the channel information of a MS-BS link can be estimated at the BS, the idea is to use a large scale antenna system with 128 active elements deployed as a uniform rectangular array exploiting elevation and azimuth beamforming to apply “massive” spatial division multiple access. Instead of increasing the SINR of few users the degrees of freedom in beamforming are used to serve as many users as possible in the spatial domain. Compared to [METIS31] variable elevation beamforming has been added. Performance evaluation using interference aware regularized ZF precoding with or without user grouping and relaxed power constraints is shown in multi-cell system-level simulations with realistic Quadriga [JBTJ12] channels.</p>
KPIs considered and Expected gain	Sum Spectral Efficiency: 10 to 20 times User Spectral Efficiency: 10 to 20 times
Performance Evaluation Approach	Simulation-based
Simulation Type	System Level
Dynamic Class	Semi-static
System Model Considered	RC-baseline
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> Model of environment: WINNER urban macro Spectrum Assumption: 18 MHz at 2.68 GHz Propagation model: Fast fading and 100% NLOS with Quadriga channels [BDJT12] Deployment model: 3 sites per BS in a hexagonal grid with an inter site distance ISD=500m User distribution: uniform random Traffic model: full buffer
Considered Legacy Solution	With fewer antennas (8 antennas) and fixed elevation beamforming CoMP in LTE-A release 11.

2.3.3 TeC complementarity analysis

As in section 2.2.3, in the following analysis TeCx is considered complementary to TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy. Note that in general the relation is not symmetric.

Considering innovations in RC 2, TeC 8 provides a solution for the system architecture and covers both the uplink and downlink direction. Therefore, it is not complementary with the other TeCs. In contrast to this, TeCs 10 and 11 are solutions for the downlink and TeC 9 for uplink only. This ensures that TeC 9 is complementary with TeCs 10 and 11. TeC 10 reduces the complexity of the transceiver and provides coordination between macro BSs so it is complementary with TeC 11 which is covering beamforming and user grouping of a single macro BS. An overview of the complementary analysis is listed in Table 2.4.

Table 2.4: T3.1 RC2 Overview of the TeC complementarity analysis

TeCx Comple ments TeCy	TeC 8 Massive MIMO and UDN	TeC 9 Multi-cell MU massive MIMO w/ max weighted sum rate	TeC 10 Decentralized Transceiver Design	TeC 11 Massive SDMA with a LSAS
TeC 8	-	No	No	No
TeC 9	No	-	Yes	Yes
TeC 10	No	Yes	-	Yes
TeC 11	No	Yes	Yes	-

2.4 Most promising concepts from Task T3.1

From T3.1 one of the key areas, which is considered to contribute to a 5G system is back haul. This may prove to be very significant due to anticipated proliferation of ultra dense networks, vehicular networks with high capacity etc. Massive MIMO for in-band backhaul is investigated in TeC 1b which utilizes mm waves and symmetric MIMO and TeC 6 which focuses on high mobility. Energy saving and improvement in spectral efficiency are expected as direct outcomes.

The other is in the access network. Massive MIMO access is considered in several TeCs. TeC7 focuses on quasi-mm waves and 3D beamforming with CSI error. The bit rates around 20Gbps can be realized at lower average SNR. TeCs 9-11 study a typical cellular configuration with reduced complexity transceiver processing. With less signalling these are expected to contribute to METIS goal in 10-100 times increased data rate.

2.5 Interactions between T3.1 and other METIS WPs

The channel models to be developed in **WP1** can be used in the simulations in all TeCs. At the moment there is a scarcity of these for massive MIMO, with the existing LTE standard covering only up to 8x8 MIMO. In addition mm wave TCs benefit from modelling at 60 GHz. New waveform designs considered in **WP2** may result in different signal models which would then have an influence in precoder and decoder designs. Many TCs consider basic OFDM scheme as the basic waveform, the effects from which then need to be modified to a certain extent in resource allocation algorithms. Results from T3.1 can be utilized in **WP4** for further resource allocation and interference management. Also interference coordination methods investigated in WP4 can have some influence on those considered in T3.1. Since mm waves and quasi-mm waves are considered, the spectrum allocation considered in **WP5** has relevance in those areas.



2.6 Conclusion

The main objective of this deliverable has been to identify the possible contributions from various TeCs to realize TC2. Accordingly the expected impact on TC2 by different TeCs has been considered and compared. In addition, individual contributions show promise in further results, e.g., RC1 delivers strong results in more practical scenarios, specifically high mobility, mm-wave and in channel modelling. mm-wave applications would produce novel solutions which also support other aspects such as ultra dense networks (UDN). RC2 focuses mostly on multicellular systems including the heterogeneous case considering detailed channel models obtaining results in simplified processing techniques. The simulation alignment exercise carried out holds the promise for obtaining more concrete solutions for TC2 from each of the RCs. Further work with more realistic channel models is expected. Massive MIMO for in-band backhaul and for access are identified as two key concepts in terms of most promising technologies from T3.1.



3 Task 3.2: Advanced inter-node coordination

3.1 General overview

Task 3.2 is in charge of the exploration of advanced inter-node coordination approaches. The advantages of cooperation have been widely discussed in literature and standardization bodies, and have been claimed to provide increased cell-edge throughput and higher system capacity, through the mitigation or even exploitation of the interference, which usually limits performance in wireless networks.

However, it is also acknowledged that this kind of solutions requires a careful design, otherwise a significant gap will be observed between the theoretically impressive gains that are expected, and those that are actually achievable under non-ideal conditions (e.g. for backhauling or feedback impairments).

Taking into account this challenging and complex background, Deliverable [METIS31] identified three main research directions for the activities in Task 3.2.

The first direction, which is explored by RC1, is devoted to further study classical coordination approaches under practical feedback and backhauling constraints, which could arise in a realistic system, and have been identified as possible game stopper for CoMP.

The second one, explored in RC2, aims to develop the novel Interference Alignment concept introduced in recent studies, which however still needs to be explored in a more realistic framework.

The third approach, examined in RC3, explores the potentiality of coordination when network elements provide novel capabilities, ranging from alternative access schemes that could lead to novel cooperation approaches, to enhancements in UEs that can alleviate the coordination burden on the network, or advancements at the network side that could be deployed in synergy with coordination approaches (e.g. Massive MIMO).

The following sections provide the description of the TeCs investigated in each Cluster, with indications of the expected gains, and of the approach and system assumptions followed to provide these preliminary results. Further details on the obtained simulation results are provided in Appendix C section 9.2. Since (TC2) “dense urban information society” [METIS61] has been identified by the METIS project as one of the most relevant TCs, a simulation baseline was defined in the Task for the TeC currently under investigation that is in line with basic assumptions in TC2; a detailed description of the agreed assumptions is available in Appendix B section 8.2.

An evaluation of the potential complementarity/alternativeness of the proposed TeCs is also here presented, together with an indication of the most promising concepts and the expected impact of the described TeCs on the other WPs in METIS.

3.2 Research Cluster 1: Further improvements to classical coordination techniques.

3.2.1 Introduction

This research cluster is focused on further studies of the classical coordination techniques (e.g. CoMP) under practical feedback and backhaul constraints. The studies herein are targeting the METIS TC2 “Dense urban information society” from [METIS11], with the objective of increasing the system spectrum efficiency and the cell-edge spectrum efficiency. Some of the main challenges evoked by this complex scenario and considered in this RC are:

- Reliable feedback links of high-capacity are unlikely to be available on a large scale due to limited bandwidth and high inter-cell interference.

- The backhaul links interconnecting multiple nodes may be wireless and unreliable. In addition, low-latency backhaul links are required for timely sharing of the CSI-based information among the coordinated transmission nodes.
- The system spectrum efficiency is mainly limited by the feedback and training overhead.

With the TeCs provided in this RC, we will be able to evaluate both numerically and theoretically how existing coordination schemes cope with feedback and backhaul delays. This allows us to find better techniques that efficiently deal with practical impairments, thus improving the system performance. Advanced precoding schemes as well as backhaul load reduction schemes, which can mitigate inter-cell interference without relying on expensive and low-latency backhaul links, have also been provided.

More details of the TeCs related to this RC are given in the next section. Table 3.1 provides a summary of the main TeC ideas.

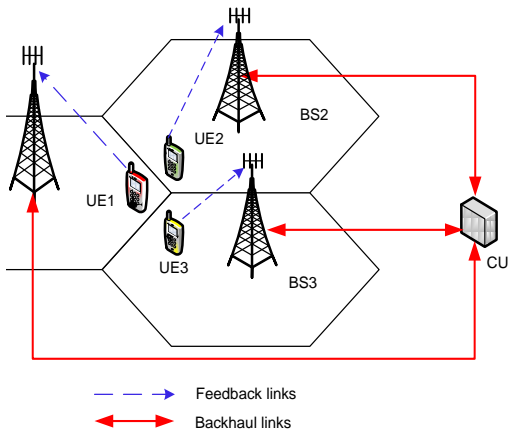
Table 3.1: T3.2 RC1 Technology Components

TeC #	Short Title	Short description
TeC 1	CoMP Resource Allocation	Investigation of the impact of feedback and backhaul links on the performance of different multi-node transmission schemes. Multi-node resource allocation is proposed under imperfect feedback and backhaul channels.
TeC 2	Exploiting temporal channel correlation to reduce feedback in CoMP	An optimal feedback period is derived such that it guarantees same spectrum efficiency as using a conventional feedback scheme.
TeC 2b	DoF of MIMO BC and IC with delayed CSIT	Theoretical analysis of the Degree of Freedom (DoF) and net DoF of recent schemes for the MIMO IC and BC with delayed CSIT (DCSIT) and finite coherence time.
TeC 3	Distributed Precoding with Data Sharing	Precoding scheme for interference mitigation in multi-cell multi-antenna systems based on local CSI and data sharing

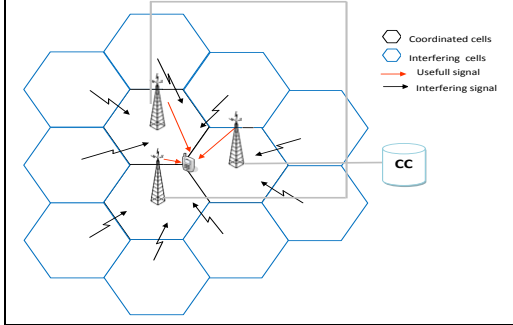
3.2.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.2 Research Cluster 1, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C section 9.2.

The structure and meaning of the different fields in the tables hereafter have been described in section 2.2.2.

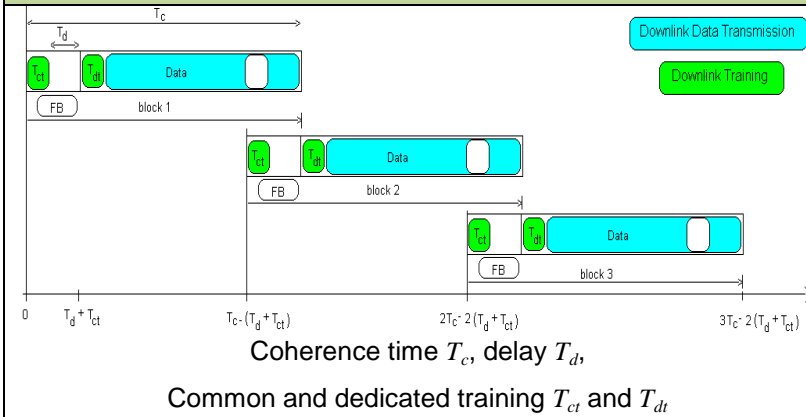
T3.2 TeC.01– Multi-node resource allocation under imperfect feedback and backhaul channels	
 <p style="text-align: center;"> —→ Feedback links ↔ Backhaul links </p>	<p style="text-align: center;">Main Idea</p> <p>First goal is to analyse the performance of multi-node joint transmission schemes with imperfect CSIT, considering the effects of feedback and backhaul latency, user mobility and feedback errors. Based on the backhaul topology, the work also considers other network architectures, e.g., semi-distributed and fully-distributed networks.</p> <p>Second goal is the design of robust precoding schemes that can achieve cooperation gains with low-complexity, for densely deployed access points with heterogeneous transmit powers and activation probability. An additional focus is put on backhaul load reduction strategies, reducing the backhaul load by using MAC layer scheduling approaches, which provide a trade-off between sum rate and backhaul use.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Cell throughput to be evaluated • Cell-edge throughput to be evaluated
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other
Deviation compared to RC Baseline	Significant: <ul style="list-style-type: none"> • Model of environment: Urban Macro Area • Spectrum Assumptions: 2GHz • Propagation model: Simplified 3GPP Case 1 • Deployment model: Hexagonal Grid • User/Device Distribution: Uniform/Random • Traffic model: Full Buffer
Considered Legacy Solution	Adapted LTE Release 11

T3.2 TeC.02 - Exploiting temporal channel correlation to reduce feedback in CoMP scheme

	<p style="text-align: center;">Main Idea</p> <p>In order to reduce the feedback update period without impacting the system throughput we exploit the channel temporal correlation. We derive an optimal feedback updating period which is triggered by the transmitters to enable the receiver to send the CSI. This updating period is a function of the channel temporal correlation (UEs speeds), available feedback bits, and the number of transmit antennas.</p>
---	---

KPIs considered and Expected gain	<ul style="list-style-type: none"> • Feedback reduction: min 16% for 50km/h to max 76% for 15km/h in the used codebook size. • The feedback scheme with longer update feedback period is compared to a scheme with feedback period equal to 1 under the condition to achieve the same total throughput.
Performance Evaluation Approach	Analytical and Simulation based
Simulation Type	Analytical and System level simulations based on simplified MIMO Block Fading Multipath AWGN Channel models with path loss. Analytical approach is used to determine the optimal feedback period and used later into the system simulator to evaluate the system throughput.
Dynamic Class	Semi-static Model
System Model Considered	RC baseline
Deviation compared to RC Baseline	Propagation and deployment model simplified
Considered Legacy Solution	LTE-A Rel.12

T3.2 TeC.02b - DoF and net DoF of recent schemes for the MIMO IC and BC with delayed CSIT and finite coherence time

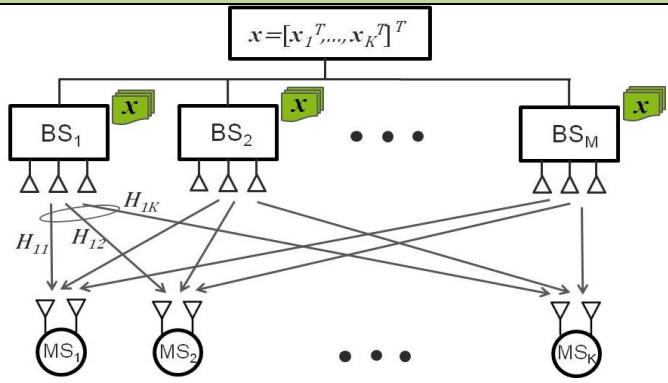


Main Idea

Theoretical analysis of the DoF and net DoF of recent schemes for the MIMO interference channel and broadcast channel with delayed CSIT and finite coherence time.

In order to overcome feedback delay and maximize the net DoF another feedback scheme was proposed based on the finite rate of innovation channel models [LSY13a]: FCFB (Foresighted Channel Feedback). It allows to have constant knowledge of the CSIT at the cost of an increase of training/feedback rate.

KPIs considered and Expected gain	<ul style="list-style-type: none"> Cell throughput in DoF (Sum rate slope at high SNR) Acceptable feedback delay (feedback delay that can be accommodated without DoF loss)
Performance Evaluation Approach	Analytical
Simulation Type	Not Applicable
Dynamic Class	Not Applicable
System Model Considered	Not Applicable
Deviation compared to RC Baseline	Not Applicable
Considered Legacy Solution	Not Applicable

T3.2 TeC.03 - Distributed precoding with data sharing	
	<p>Main Idea</p> <p>Develop precoding strategies which utilize local CSI and exploit some form of data sharing among the BSs (e.g. the presence of caching mechanism in the BSs that stores frequently downloaded content) in order to mitigate the interference, and relaxing the backhauling requirements.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> Average cell-edge spectral efficiency. Expected Gain: 0-300% (dependent on the system configuration). 0% refers to the low SNR range where existing solutions or MRT can be utilized.
Performance Evaluation Approach	Analytical / Simulation-based
Simulation Type	Simplified system level simulation
Dynamic Class	Semi-static model
System Model Considered	Simplified RC1-baseline with normalized flat-fading channels. Implicit assumption taken from the T3.2-RC1 baseline is the large backhaul latency value (50 ms) which prevents timely distribution of the collected local CSI.
Deviation compared to RC Baseline	As the current focus is on the algorithms for the optimal precoders, we use the normalized block flat-fading Rayleigh channel model with complex Gaussian i.i.d. zero-mean and unit-variance coefficients. Future work will include more realistic scenarios.
Considered Legacy Solution	Relevant works from the literature for the considered case, as described in the appendix, see section 9.2.4 (LTE baseline to be considered in the future work)

3.2.3 TeC complementarity analysis

As explained in section 2.2.3, TeCx is considered complementary to TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy.

In RC 1 TeCs 1, 2 and 2b investigate how existing coordination schemes cope with feedback delays, in particular:

- The performance evaluation approach used in TeC 1 is simulation based and could be extended to include TeC 2 proposal.

- TeC 2 offers a way to balance feedback size and update rate. The proposed strategy could be assessed together with TeC 1 and could be exploited also in TeC 3.
- TeC 2b adopts an analytical approach that could be extended to assess the performance of all the other TeCs in RC1.
- TeC 3 targets for relaxing backhauling requirements. It provides a distributed precoding scheme with only local CSI sharing so its applicability with other TeCs is limited. Table 3.2 summarizes the outcome of the complementarity analysis.

Table 3.2: T3.2 RC1 Overview of the TeC complementarity analysis

TeCx Comple ments TeCy	TeC 1 CoMP Resource Allocation	TeC 2 Exploiting temporal channel correlation to reduce feedback	TeC 2b DoF of MIMO BC and IC with delayed CSIT	TeC 3 Distributed Precoding with Data Sharing
TeC 1	-	Yes	No	No
TeC 2	Yes	-	No	Yes
TeC 2b	Yes	Yes	-	Yes
TeC 3	No	No	No	-

3.3 Research Cluster 2: Studies on Interference Alignment

3.3.1 Introduction

This research cluster is based on two main objectives. The first objective is to provide interference alignment (IA) based transmission schemes for large cellular systems and real world scenarios. The second is to further explore the potentials of IA based schemes using the information-theoretic tools. Hence it is a good mix of solutions (evolution and innovation) to the problem space of interference in cellular networks based on the concept of IA.

The main problems that are in focus in this RC are highlighted as follows:

- In a multi-user multi-cell MIMO network, we deal with a space of interference which has multiple dimensions and only a limited number of degrees of freedom are available at the receivers. Partial IA can be one of the sub-optimal solutions.
- Exploitation of user selection diversity for the performance improvement of IA based transmission schemes.
- Distributed IA schemes for MIMO IC are attractive and provide close to optimal performance. However, their convergence time and required overhead are an issue which needs further considerations and research.

The TeCs in this research cluster target multiple TCs.. The TC2 (Dense urban information society), TC 3 (Shopping Mall), TC 4 (Stadium) and TC 9 (Open Air Festival) are the most interesting TCs where the solutions are applicable with a reduced effort. The TeCs enable the use of IA in diverse scenarios depending upon the availability of infrastructure. Main targets of the TeCs in these TCs are to improve the system spectral efficiency as well as to reduce the complexity. Further descriptions related to the main idea, performance metric, methodology and other impacts of each individual TeC are given in the following section. Table 3.3 provides a summary of the main TeC ideas.

Table 3.3: T3.2 RC2 Technology Components

TeC #	Short Title	Short description
TeC 4	Multi-User Inter-Cell Interference Alignment (MUICIA)	Design of multi-user selection algorithms in an OFDM based closed loop downlink transmission system. The transmit-precoding scheme is based on interference alignment in a multi-user multi cell network where both

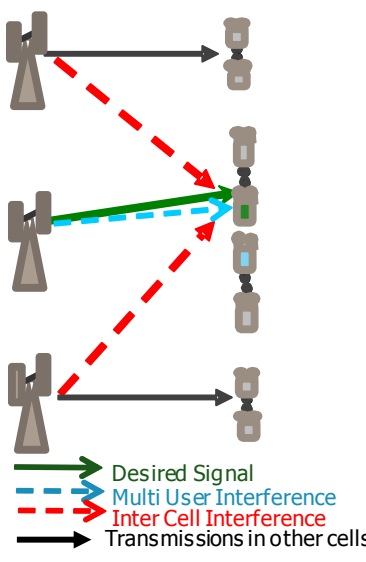


TeC #	Short Title	Short description
		the transmitters and the users are equipped with multiple antennas.
TeC 5	Semi-distributed IA with PC convergence speed up	Semi-distributed algorithm to find the optimal filters at the BSs and UEs that achieve a target SINR at each UE, with power control (PC) to reduce the number of iterations and check the existence of the optimal solution at the beginning.
TeC 6	Distributed schemes for MIMO ICs	The proposed schemes rely on forward-backward training in TDD systems, to iteratively refine both the transmit and receive filters. They also employ a so-called turbo iteration run at each transmitter / receiver to speed up the convergence.

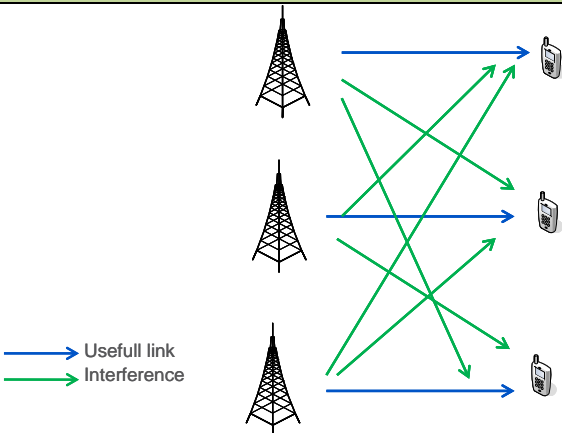
3.3.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.2, RC 2, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C section 9.2.

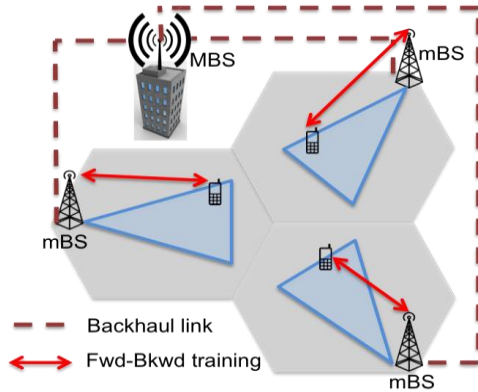
The structure and meaning of the different fields in the table have been described in section 2.2.2.

T3.2 TeC.04 – Real world interference alignment	
 <p> → Desired Signal - - - Multi User Interference - - - Inter Cell Interference → Transmissions in other cells </p>	<p style="text-align: center;">Main Idea</p> <p>The main idea is to find algorithms for user selection that maximises the performance of multi-user IA based transmit precoding, in order to maximise the system spectral efficiency.</p> <p>The approach is to find a pair of users that can benefit most from the alignment technique that aims to align intra-cell and inter-cell interference. Such a pair provides high system performance when IA is applied as transmission technique.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> System Spectral efficiency: average gain from 20% to 45%
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other
Deviation compared to RC Baseline	Some: <ul style="list-style-type: none"> Model of environment: Urban Macro Area Spectrum Assumptions: 2.0 GHz Propagation model: 3GPP SCM Deployment model: Hexagonal Grid User/Device Distribution: Uniform Traffic model: Full Buffer
Considered Legacy Solution	Adapted LTE Release 11

T3.2 TeC.05 - Semi-distributed IA algorithm for MIMO-IC channel, with power control convergence speed up

	<p style="text-align: center;">Main Idea</p> <p>We propose a distributed algorithm to find the optimal filters at the BSs and UEs enabling to reach a set of target signal to interference plus noise ratios (SINRs) at the different streams of the different links in the network. In a second step, we propose to allow a limited information exchange at a Central Unit (CU) level, that is used to alleviate the complexity of the distributed algorithm and to adapt the choice of target SINRs. Only the information needed to check the existence of an optimum power allocation to reach a target SINRs are sent to the CU. The CU computes this optimal power allocation when it exists. The proposed algorithm is shown to decrease the iteration number to reach the target SINRs and to have quasi-optimal performance.</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • Higher Spectral efficiency due to IA • Reduced complexity (due to higher convergence speed allowing reduced number of iterations): from x2 to x100.
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>Simplified system level evaluation</p>
<p>Dynamic Class</p>	<p>Static model</p>
<p>System Model Considered</p>	<p>other</p>
<p>Deviation compared to RC Baseline</p>	<p>Not Applicable. The system model consists of a simple K-user MIMO IC, with narrowband flat fading.</p>
<p>Considered Legacy Solution</p>	<p>IA with minimum leakage algorithm [YTJ+08]</p>

T3.2 TeC.06 – Distributed low-overhead schemes for MIMO ICs



MBS - Macro Base Station
mBS - micro Base Station

Main Idea

The proposed schemes rely on forward-backward training in TDD systems, to deliver high spectral efficiency, while still requiring a low communication overhead associated with the F-B iterations. Relatively high performance are achieved solving a relaxation of the original leakage minimization problem, and also thanks to the introduction of a so-called turbo iteration, where each transmitter / receiver further refines its filter, thus greatly speeding up the convergence.

KPIs considered and Expected gain	Gain in average sum-spectral efficiency (in bps/Hz) increases with decreasing noise level, and increasing system dimensions (e.g. antennas, users, cells). Expected gain over baseline is ~20% in the medium noise level (~ -20dB), and ~90% in the low-noise regime (~ -40dB)
Performance Evaluation Approach	Simulation based
Simulation Type	Simplified system level evaluation (physical layer only)
Dynamic Class	Static model
System Model Considered	Other
Deviation compared to RC Baseline	Not Applicable. The system model consists of a simple K -user MIMO IC, with narrowband flat fading.
Considered Legacy Solution	Distributed Interference Alignment algorithm [GCJ08]

3.3.3 TeC complementarity analysis

As in section 2.2.3, TeCx is considered complementary to TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy.

TeC 4 targets the problem of both ICI and multi-user interference (MUI) and provides linear solutions based on un-coordinated IA. The solution is most suitable for an FDD based system and requires no coordination between the cells. This solution can be applied in a multi-user MIMO cellular network where each transmitter is sending single-layer streams towards multiple users.

TeC 6 on the other hand targets the problem of ICI and provides the iterative solutions based on distributed IA. The solution is most suitable for a TDD based system and requires coordination between the cells. This solution can be applied in a clustered cellular network where each transmitter is performing single user MIMO transmission. So TeC 4 and TeC 6 have different assumptions on the considered setup and limited possible interactions.

TeC 5 on the other hand could be used to speed up the convergence of iterative approaches, assuming that a certain level of cooperation is possible, so it can complement TeC6.

A compact complementary analysis is given in Table 3.4 hereafter.

Table 3.4: T3.2 RC2 Overview of the TeC complementarity analysis

TeCx Complements TeCy	TeC 4 Multi-user Inter-Cell IA	TeC 5 Semi-distribute IA with PC	TeC 6 Distributed schemes for MIMO ICs
TeC 4	-	No	No
TeC 5	No	-	Yes
TeC 6	No	No	-

3.4 Research Cluster 3: Coordination with enhanced network and UE capabilities

3.4.1 Introduction

This RC deals with novel approaches to coordination that exploit enhanced capabilities available in the network or UEs. In particular TeCs here considered can be divided in:

- coordination techniques that exploit enhancement in the UEs,
- techniques that require enhancement also in the network.
- techniques that are based on the use of alternative access scheme.

Research based on UE enhancement aim to alleviate the coordination complexity burden on the network, allowing e.g. to have simpler clustering techniques thanks to enhanced cancellation capabilities of multi-antenna UEs that can tolerate higher inter-cluster interference (TeC 7), or reducing the feedback requirements thanks to channel prediction algorithm in the UE receiver (TeC 10). Also improved performance can be achieved when the interference capabilities of UEs are assisted by a network that provides interference information or transmission points coordination (TeC 12).

Technology components that exploit advanced capabilities in the network consider techniques, as Massive MIMO (TeC 13) or relayed communications (TeC 14), that are under study in other Tasks of the WP, or develop coordination approaches that leverage advanced switch off capabilities of transmitting nodes to reduce the overall power consumption (TeC 15).

Alternative access schemes considered are Non-Orthogonal Multiple Access (TeC 8), non-coherent transmission schemes (TeC 16) and a decentralized access scheme suitable for D2D communications (TeC 11). For the first two this phase of the research is basically investigating the potential of these schemes and ways in which coordination can be used to improve them. The third one proposes a decentralized interference aware scheduling mechanism based on beacon signals sent from the UE that is applicable to extremely dense deployments, D2D communications and the likes, to solve outages arising from harsh interference. A more detailed overview of the technology components related to RC3 is given in the next section. Table 3.5 provides a summary of the main TeC ideas.

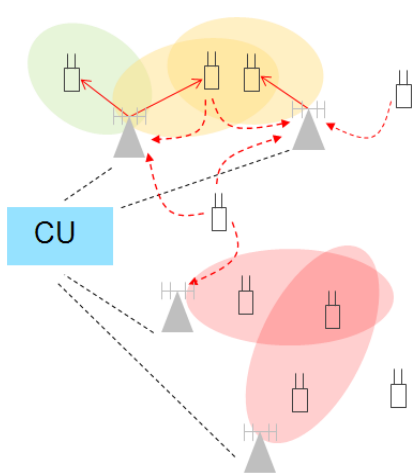
Table 3.5: T3.2 RC3 Technology Components

TeC #	Short Title	Short description
TeC 7	Dynamic Clustering with Multiantenna Receivers (DCMR)	Develop a dynamic BS clustering and UE scheduling for downlink CoMP systems where the resource allocation scheme explicitly considers that UEs are equipped with multiple antennas.
TeC 8	NOMA	Non Orthogonal Multiple Access (NOMA) with multi-antenna transmission schemes.
TeC 10	Distributed JT-CoMP	Distributed JT-CoMP downlink based on limited CSIT in a dense FDD network with enhanced multi-antenna receive processing
TeC 11	DIAS	Decentralized interference aware scheduling (DIAS) approach suitable for D2D communication, based on the transmission of a reverse beacon to signal interference.
TeC 12	NA IS/IC receivers and ultra-dense networks	Network-assisted co-channel interference robust receivers for dense cell deployments
TeC 13	Interference mitigation based on JT CoMP and massive MIMO	In ARTIST4G a powerful interference mitigation framework has been developed based on joint transmission CoMP beside others for a 4x2 MIMO scenario. Identified limitations like limited coverage for indoor users and rank deficiencies in case of many simultaneously served users should be overcome by proper inclusion of small cells and massive MIMO.
TeC 14	Coordinated scheduling for two-way relaying with NC.	In this work we apply the coordinated scheduling approach for the two-way relaying with network coding (NC) and MIMO in TDD systems
TeC 15	Adaptive and energy efficient dense small cells coordination	Define coordination schemes that allow to switch off unnecessary small cells when traffic request is low
TeC 16	Non-coherent communication in coordinated systems	This work investigates non-coherent communication in systems where the users are connected to multiple transmission points.

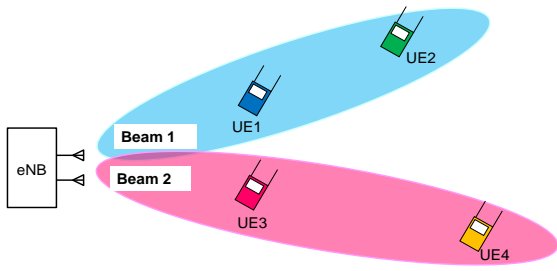
3.4.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.2 RC 3, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C section 9.2.

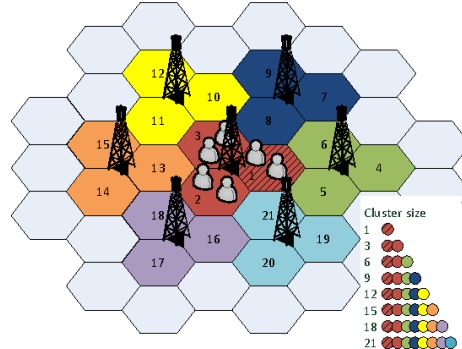
The structure and meaning of the different fields in the table have been described in section 2.2.2.

T3.2 TeC.07 - Dynamic clustering with multiple receive antennas in downlink CoMP systems	
	<p style="text-align: center;">Main Idea</p> <p>The work considers a dynamic clustering and scheduling algorithm. The algorithm allows a dynamic optimization, in each time slot, of the set of non-overlapping clusters and the UEs scheduled within each cluster, maximizing the network weighted sum rate. The approach is extended to the case where the UEs are equipped with multiple antennas and exploit them either to implement an interference rejection combiner or to be served by multi-stream transmission.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Cell throughput: average gain from 10% to 20% • User throughput: 5th perc. gain from 30% to 50% • Spectral efficiency: average gain from 10% to 20%
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other
Deviation compared to RC Baseline	<p>Some:</p> <ul style="list-style-type: none"> • Model of environment: Urban Macro Area • Spectrum Assumptions: 2.6 GHz • Propagation model: Simplified 3GPP Case 1 • Deployment model: Hexagonal Grid • User/Device Distribution: Uniform • Traffic model: Full Buffer
Considered Legacy Solution	Adapted LTE Release 11

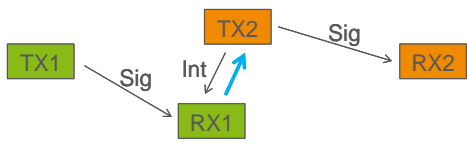
T3.2 TeC.08 - Studies on Non-Orthogonal Multiple Access (NOMA)

<p style="text-align: center;">System Model</p>  <p>Multi-user MIMO setting. BS and UEs have multiple antennas. Communications rely on a combination of multi-antenna transmission and non-orthogonal methods. Inter-site interference coordination is also considered.</p>	<p style="text-align: center;">Main Idea</p> <p>The main idea is to combine non-orthogonal multiple access (NOMA) schemes [METIS22] with multi-antenna transmission schemes.. One example is to use multiple antennas at the transmitter to form multiple beams and within each beam, multiple users are multiplexed using a non-orthogonal multiple access based technique.</p> <p>This idea will be extended to multi-site operations by introducing inter-site interference coordination (e.g., in frequency, space and/or power domains).</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • Cell Throughput, Expected Gain (20%~40%). • Cell-Edge Throughput, Expected Gain (20%~40%)
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>System Level Evaluation</p>
<p>Dynamic Class</p>	<p>Semi Static model</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Medium</p> <ul style="list-style-type: none"> • Model of environment: Urban Macro, SIMO 1x2 • Spectrum Assumption: Carrier frequency 2 GHz. System Bandwidth 10 MHz • Propagation model: 3GPP Spatial Channel Model (SCM) Urban Macro, Correlated shadowing. • Deployment model: Hexagonal grid, 19 sites, 3 cells per site, ISD 500m. • User distribution: uniform random, UE speed max 3 km/h. • Traffic model: full buffer traffic
<p>Considered Legacy Solution</p>	<p>LTE radio interface but with 1x2 for these initial evaluations</p>

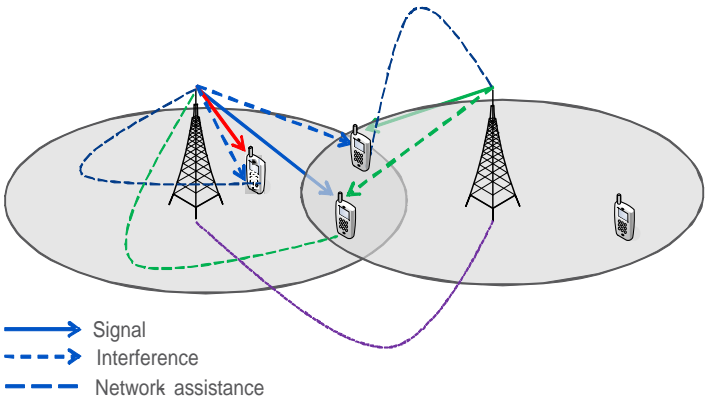
T3.2 TeC.10 - A system-level study on multi-user MIMO transmission for dense FDD networks

 <p>Network-centric cluster topology, where the cluster size is increasing by a full site, i.e. 3 sectors, in a step-wise analysis.</p>	<p>Main Idea</p> <p>The need for cell densification leads to inter-cell interference mitigation techniques known as CoMP transmission and reception. In this work, we start from the weighted sum-rate maximization problem by evaluating the capacity of the broadcast channel (BC). We employ non-linear Dirty Paper Coding (DPC) on a cluster basis with additional Co-Channel Interference (CCI) caused from surrounding BSs. These results characterize the capacity of the BC under cellular propagation conditions. Subsequently, we summarize multi-cell simulation results assuming linear precoding and non-ideal clustering as well as user grouping. For downlink precoding we compare the well-studied limited feedback assumption, Zero Forcing (ZF) beamforming for joint transmission downlink CoMP and compare their resulting sum-rates with the derived BC capacity</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • Sum-data rate under evaluation • User data rate under evaluation • User outage probability under evaluation
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>System Level</p>
<p>Dynamic Class</p>	<p>Semi-static</p>
<p>System Model Considered</p>	<p>RC-baseline</p>
<p>Deviation compared to RC Baseline</p>	<p>Medium:</p> <ul style="list-style-type: none"> • Model of environment: WINNER urban macro • Spectrum Assumption: 18 MHz bandwidth (100 RBs) at a centre frequency of 2.68 GHz • Propagation model: Fast fading with QUADRIGA 100% NLOS • Deployment model: 3 BS per site in a hexagonal grid with an ISD=500m without small cells • User distribution: uniform random • Traffic model: full buffer
<p>Considered Legacy Solution</p>	<p>CoMP in LTE-A</p>

T3.2 TeC.11 - Decentralized interference aware scheduling

 <p>D2D communications with TDD transmission</p>	<p style="text-align: center;">Main Idea</p> <p>The work proposes a decentralized interference aware scheduling approach, where TDD subframes are split into a data phase and a beacon phase. During the beacon phase, each data receiver transmits with a predefined power a beacon message that contains three quantities encoded into it: the received signal power, the received interference + noise power and the perceived average throughput. Each transmitter receives the beacon messages from the surrounding receivers and uses this information to infer the impact of its own scheduling decisions to the neighbouring interference victims. In this way the scheduling decision can improve the system level utility instead of maximizing just the single link utility.</p>
<p>KPIs considered and Expected gain</p>	<p>Coverage: possibility to reach highly interfered users far away from the transmitter (which are not reachable with legacy solution). See Appendix C section 9.2.11.. Mean throughput: Expected Gain +5% (so no loss due to the distributed D2D approach)</p>
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>System level evaluation</p>
<p>Dynamic Class</p>	<p>Semi-static</p>
<p>System Model Considered</p>	<p>Other from RC baseline</p>
<p>Deviation compared to RC Baseline</p>	<p>Not Applicable. D2D communication scenario not yet implemented. To emulate D2D, where transmission is not necessarily directed to the closest receiver, an indoor scenario is used, where UEs are served by the BS that belongs to the same closed subscriber groups (CSG), which may not be the closest BS. System parameters are:</p> <ul style="list-style-type: none"> • SISO transmission • (extended) WINNER2 A1 scenario. 2 floors, 4 buildings, 4 BS per floor; 3 UEs per BS on average • Frequency selective fading as in WINNER2 A1 • Closed subscriber groups :2 CSGs per floor, 2 BS per CSG per floor • Full buffer traffic model • TDD system, 24MHz bandwidth, subframe 1ms. For DIAS: split into 0.9ms data and 0.1ms beacon phase. For conventional Proportional Fair (PF): 1ms data
<p>Considered Legacy Solution</p>	<p>Non interference aware Proportional Fair scheduling in BS</p>

T3.2 TeC.12 – Network-assisted interference suppressing/cancelling receivers and ultra-dense networks



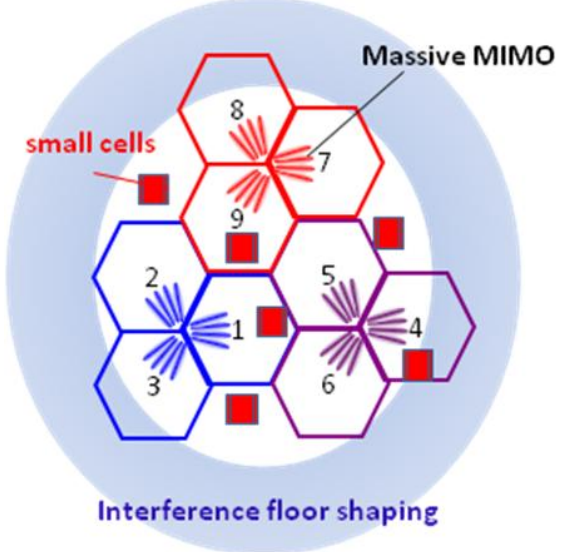
Main Idea

The work proposes the introduction of network assistance (NA) to further enhance the co-channel inter- and intra-cell interference mitigation ability of UE receivers.

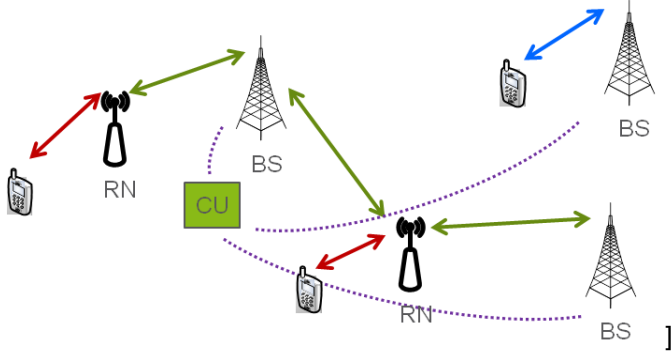
Network assistance, in forms of interference signal parameter signalling and/or network side transmission coordination, should improve the interference estimation accuracy and consequently the interference suppression and cancellation (IS/IC) performance of NA-enabled UE receivers. The improved interference robustness, in terms of higher effective post-IS/IC SINR, enables higher user throughput / network capacity and increased spectral-efficiency in co-channel interference limited networks.

KPIs considered and Expected gain	<ul style="list-style-type: none"> Obtained simulation results indicate SINR gain, over that of the non-NA baseline receiver, ranging from 0.5 dB up to 3 dB for E-LMMSE-IRC, depending significantly on the interference profile studied. Furthermore, for specific high INR interference profiles SLIC showed up to 1.5 dB gains over E-LMMSE-IRC. In case of L-CWIC, with low aggressor MCS#, even more sizeable gains in specific interference scenarios are possible.
Performance Evaluation Approach	Simulation-based
Simulation Type	Multi-link level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other
Deviation compared to RC Baseline	Not Applicable. Current analysis performed on link-level.
Considered Legacy Solution	Rel-11 IS LMMSE-IRC receiver operation (without NA)

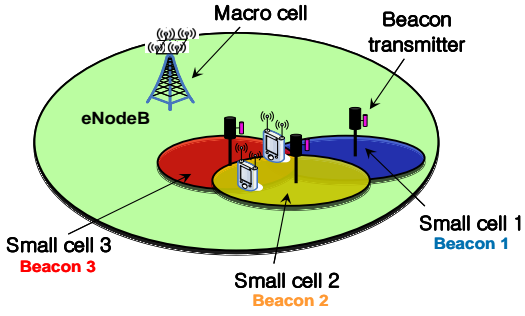
T3.2 TeC.13 – Interference mitigation based on JT CoMP and massive MIMO

 <p>Target scenario for inclusion for massive MIMO and small cells into interference mitigation framework. Interference floor shaping decouples cooperation areas allowing for extended multi-link optimizations.</p>	<p>Main Idea</p> <p>Starting from a 4x2 MIMO scenario comprising 9 cells forming a single cooperation area the number of TX antennas is gradually increased to analyse the according performance gains. Focus is on residual inter-cell interference for realistic number of antenna elements and the best to leverage the potential of the extra antennas. The goal is to exploit installed base station and installed hardware as far as possible. This has to be compared to a pure massive MIMO strategy, with strong over-provisioning of antenna elements, with according potential issues for cost and size of the antenna arrays.</p>
--	--

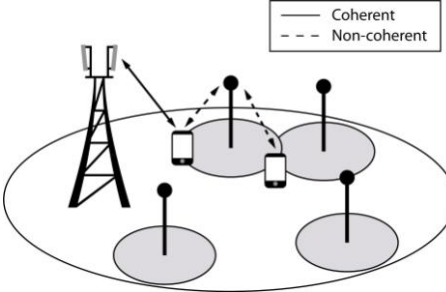
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Spectral efficiency: Expected Gain > 100% to ideally factor of 10 over LTE Release 8 • Capacity gain: factor of 10 to 100 with increasing number of small cells
Performance Evaluation Approach	Simulations / partly Analytical
Simulation Type	Extended link or multi-link level simulations for single cells and single cooperation areas comprising typically three to nine cells
Dynamic Class	Nomadic users
System Model Considered	<p>a) Building vector data map for Munich NSN campus</p> <p>b) 3GPP case 1, 2.6GHz, only outdoor users</p>
Deviation compared to RC Baseline	<ul style="list-style-type: none"> • Model of environment: wide area outdoor • Spectrum Assumptions: 2.6GHz • Propagation model: 3GPP case 1 / ray-tracing • Deployment model: Wide Area only as well as in combination with small cells • User/Device Distribution: uniform • Traffic model: full buffer
Considered Legacy Solution	LTE Release 11 as baseline assumption with extensions for supported number of antenna elements (>8x8), extra reporting of CSI, novel concepts for Broadcast Channel (BCH) and control signal broadcasting, novel concepts for channel estimation

T3.2 TeC.14 - Joint dynamic clustering and coordinated scheduling for relaying with physical layer network coding	
	<p style="text-align: center;">Main Idea</p> <p>The aim is to jointly form clusters and schedule users in a dynamic way in a TDD system with MIMO-NC relaying to mitigate the interference introduced by reversed mode of operation of relayed UEs.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Cell throughput: Under investigation • User throughput: Under investigation • Spectral efficiency: Under investigation
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Semi-static model
System Model Considered	Other Seven macro sites (3 cells per site) with hexagonal layout with wrap-around. UEs are randomly deployed per drop. 1 to 12 relays per cell.
Deviation compared to RC Baseline	<ul style="list-style-type: none"> • Model of environment - Urban macro area • Spectrum Assumptions - frequencies up to 6 GHz • Propagation mode - WINNER+ propagation model • Deployment model – hexagonal grid with 7 macro sites (21 BSs) and 1 to 12 Relay Nodes (RNs) per cell • User/Device Distribution - uniform • Traffic model – full buffer
Considered Legacy Solution	The existing 3GPP LTE system (Rel-10/11) with a reasonable density of access points (eNB, Relay, HeNB/WiFi) and certain specified Radio Resource Management (RRM) schemes (e.g., proportional fair scheduling, partial frequency reuse, eICIC) can be considered as legacy networks.

T3.2 TeC.15- Adaptive and energy efficient dense small cells coordination

	<p>Main Idea</p> <p>The work proposes the introduction of a beacon signal that can be used to facilitate the usage of CoMP schemes in presence of several dense small cells.</p> <p>The beacon should help the system in the creation of cooperation clusters, in complex scenario with high degree of cell density, allowing the detection of small cells that are in sleep mode and switching them on for CoMP transmission. In that way, the beacon allows the possibility to build CoMP scheme with small cells that can be quickly switched on or off depending on traffic demand, so that power consumption can be controlled.</p> <p>A centralized scheduling algorithm that exploits the information provided by the beacons and allows to minimize the number of active base stations, adaptively using a Joint Transmission or Dynamic Point Selection (DPS) approach,</p>
---	---

KPIs considered and Expected gain	Energy Efficiency up to +27% can be achieved in the RC baseline scenario with nowadays nodes power consumption models. Higher gains are expected with higher small cells density (e.g. in the Stadium Scenario) and improved switch off mechanisms.
Performance Evaluation Approach	Simulation-based
Simulation Type	System Level Evaluation
Dynamic Class	Semi-dynamic model
System Model Considered	RC-baseline for preliminary evaluation. Target scenario is the Stadium test case
Deviation compared to RC Baseline	<p>Some:</p> <ul style="list-style-type: none"> • Traffic model – Non-full buffer • single sector micro BS • simplified small scale fading effects • SISO system • no wrap around considered <p>More realistic simulations will be delivered for the Stadium scenario</p>
Considered Legacy Solution	Deployment without centralized coordination.

T3.2 TeC.16 – Non-coherent communication in coordinated systems	
 <p>Exemplary architecture for evaluation: HetNet with macros and small cells, a user has a coherent connection with the macro and a non-coherent connection with the small cell.</p>	<p style="text-align: center;">Main Idea</p> <p>This work investigates the use of non-coherent communication schemes, which perform data detection without any knowledge of the channel coefficients, to minimize the waste of resources due to the use of reference signals in pilot-based channel estimation.</p> <p>It evaluates non-coherent schemes over architectures where the users are connected to multiple transmission points (TP) and may receive different kind of information from each TP (e.g. HetNets using phantom cells). In addition, this TeC will be evaluated in vehicular networks, where mobility has a deep impact on performance. In both frameworks, the main goals are to explore the advantages of non-coherent communication under realistic scenarios and, also, to enable multi-user non-coherent communication.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • FER, Expected Gain of 2-6 dB in the FER vs SNR curve
Performance Evaluation Approach	Simulation-based
Simulation Type	Multi-link link level
Dynamic Class	Static model
System Model Considered	Other
Deviation compared to RC Baseline	<p>Not Applicable</p> <p>At the moment we are still doing exploratory research with a simplified system model. We assumed a transmission through block-fading Rayleigh channels, containing Gaussian i.i.d. elements with zero mean and unit variance. In a later phase, we will include more realistic channel models including time and frequency selectivity.</p>
Considered Legacy Solution	LTE-MIMO 2x2, Open-loop transmit diversity through space-frequency block coding

3.4.3 TeC complementarity analysis

Table 3.6 describes the complementarity analysis for the TeCs provided in RC3. As in previous sections, TeCx is considered complementary to TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy. Technology components in the table have been grouped according to the previously described division into techniques that exploit enhanced UEs, enhanced networks or that use alternative access schemes. It can be observed that in general, approaches that exploit enhancements in the UEs are complementary with each other: Even if they are based on different features (multiantennas in TeC 7, interference cancellation in TeC12, channel prediction capabilities in TeC 10) they could efficiently interwork. In most cases, they can also be used with TeCs that are based on network enhancements, however, it should be noted that particularly in the case of TeC 13 that addresses an interference management framework, the advantages of TeCs that enhance interference suppression at the UE (as TeC 7 and particularly TeC 12) will not geometrically sum up, but they will rather work jointly to provide an interference free reception. TeC 15 provides an energy efficient approach to CoMP in low load condition that can be used

together with most of the TeCs in the RC. TeCs based on alternative access schemes on the other hand provide novel approaches that will be difficult to deploy in conjunction with the other TeCs, also because the analysis in these cases is still on a preliminary phase. The only exception is TeC 8 based on Non Orthogonal Multiple Access (NOMA), which could benefit from TeCs that help in reducing the amount of interference that the non-orthogonal scheme inherently produces.

Table 3.6: T3.2 RC3 Overview of the TeC complementarity analysis

TeCx Complements TeCy	TeC 7 CoMP+ multiant RX	TeC 10 JT chann pred	TeC 12 NAIC	TeC 13 IMF-A	TeC 14 NW Coding	TeC 15 En Eff SC	TeC 8 NOMA	TeC 11 DIAS	TeC 16 Non Coher.
TeC 7	-	Yes	Yes	Yes	Yes	Yes	Yes	No	No
TeC 10	Yes	-	Yes	Yes	Yes	Yes	No	No	No
TeC 12	Yes	Yes	-	No	Yes	Yes	Yes	No	No
TeC 13	Yes	Yes	No	-	No	Yes	Yes	No	No
TeC 14	Yes	Yes	Yes	No	-	Yes	No	No	No
TeC 15	Yes	Yes	Yes	Yes	Yes	-	Yes	No	No
TeC 8	Yes	No	Yes	Yes	No	Yes	-	No	No
TeC 11	No	No	No	No	No	No	No	-	No
TeC 16	No	No	No	No	No	No	No	No	-

Enh. UE

Enh. NW

Alt. Access

3.5 Most promising concepts from Task T3.2

Task 3.2 has investigated different approaches in the first part of the METIS project, and some TeCs have already shown the potential to bring significant advantages in the future system, namely:

- CoMP with advanced UE capabilities; UE enhancements can alleviate the coordination complexity burden on the network, allowing to have simpler clustering techniques thanks to enhanced cancellation capabilities of multi-antenna UEs (TeC7), or reducing the feedback requirements thanks to channel prediction algorithm in the UE receiver (TeC10, TeC1), or also improving performance thanks to interference capabilities of UEs, assisted by a network that provides interference information or transmission points coordination (TeC12).
- CoMP with Massive MIMO; Massive MIMO can become an attractive complement in an interference management framework, overcoming some of the limitations identified with traditional antennas (limited coverage for indoor users and rank deficiencies for large number of simultaneous users) (TeC13). The potential interactions with TeCs from T3.1 should be therefore analysed and exploited.

Other approaches have also shown to be interesting, even if they still need further investigations to reach full maturity and be available in a realistic system. Preliminary studies on Interference Alignment (TeC4, TeC6) have shown that the technique can provide significant gains with reduced information exchange between transmitting nodes in highly interfered scenarios, if a very good signal to noise ratio could be achieved. Similarly, if caching mechanisms will become largely available in future networks, new techniques can be considered that exploit this feature to provide coordination gains with limited backhauling requirements (TeC 3).



3.6 Interactions between T3.2 and other METIS WPs

Table 3.7 summarizes the expected level of interactions between Task 3.2 and the other METIS WPs.

Interactions between T3.2 and WP1 will be limited, and mainly due to the channel assumptions and channel measurements availability that will derive from **WP1** work, which can have an impact on the different considered coordination techniques.

Most of the TeCs in Task 3.2 consider OFDMA as an air interface, but in several cases a change in the air interface due to **WP2** activities will just affect the achievable rate, without major changes in the implementation of the proposals. However, for certain TeCs the definition of new waveforms and modulations can change the design of precoding and user grouping schemes and affect research investigations in that direction.

All the proposed schemes in T3.2 target interference limited-scenarios, therefore a close alignment is needed with **WP4**, where RRM based interference coordination schemes are treated on a larger time-scale. Proposals in WP4 can imply architectural and signalling development that could bring advantages also for multi-node coordination, for example Interference identification (TeC1: New interference estimation techniques) in WP4 could bring significant benefits to interference alignment and to cancellation techniques in T3.2.

Spectrum decisions from **WP5** affect the performance achieved by the proposed schemes in T3.2, as different bands are characterized by different channel propagation conditions. However, most of the proposed schemes target frequencies where interference is the limiting factor, i.e., mainly frequencies below 6 GHz, where limited interaction will be needed with WP5. At higher frequencies, on the other hand, (e.g 60 GHz) completely different characteristics can be expected with respect to, e.g. of the mutual interference between radio stations or multi-antenna precoding design.

Interactions with **WP6** will be due mainly to system level evaluation-activities that will be needed to properly evaluate the proposed TeCs in the METIS framework. Some techniques can have architectural implications that could be discussed with WP6, for example, some TeCs assume the existence of a CU that performs the coordination, or stringent feedback and backhauling requirements, or rely on the existence of caching mechanism in the network.

Table 3.7: Interactions between T3.2 and METIS WPs

	WP1	WP2	WP4	WP5	WP6
Task 3.2	Small	Small	High	Moderate	Moderate

3.7 Conclusion

This section summarized preliminary results obtained in the advanced inter node coordination task, and highlighted the most promising concepts that have been presented in Task 3.2 during the first part of the Metis project.

Results here collected show that cooperation approaches allow improvements to the average spectral efficiency and cell-edge throughput of the system, thus also increasing the overall fairness of the system.

Possible interactions between different technologies have been identified, together with the expected impact of the considered approaches on the other Metis WPs. Appendix A further elaborates on the possible benefits that the proposed innovations can bring on the different TCs, highlighting specific aspects that can be solved with the available TeCs. Future activities will further refine the obtained results, matching them more tightly to the specific TCs currently under study in METIS.



4 Task 3.3: Multi-hop communications/wireless network coding

4.1 General overview

The research activities in T3.3 are built around two RCs. The first research cluster is devoted to infrastructure-based relaying and wireless backhauling. The second research cluster is devoted to infrastructure-less / infrastructure-assisted D2D and mobile relays.

Preliminary results for all technology components are described in section 4.2.2 for RC 1 and in section 4.3.2 for RC 2. RC 1 is building solutions for spectrally efficient network densification. Preliminary results show high promises in the use of network coding applied to increase the performance of wireless backhauling. Non-orthogonal transmission techniques and buffer-aided relaying point towards a further enhancement in spectral efficiency in relay-based communication. Those aforementioned techniques target lower frequencies (below 10GHz). TeC2 targets an indoor environment with a mm-wave mesh network where new algorithms for joint routing and resource allocation are developed.

RC 2 has further developed solutions to enable D2D communications through a relay, where the D2D communication can be an underlay network. On the other hand, research cluster 2 also examines cooperation between D2D and a cellular network. Furthermore, a study on coverage extension exploiting D2D communication has been concluded. Lastly, a new study investigates distributed MIMO transmission techniques from multiple devices in a car.

In sections 4.2.3 and 4.3.3, an analysis is provided examining the interactions of the different TeCs in the same research cluster. More specifically, the analysis focuses on the enhancement that a given TeC can bring to another TeC.

In the appendix, Section 7 details the impact of the TeCs on the test cases and summarizes how the TeCs address a test case. This analysis shows a predominant impact on TC2 for research cluster 1, while the impact of research cluster 2 is more spread as each TeC targets a different test case.

Test case 2 (TC2) "dense urban information society" has been identified by the METIS project as one of the test cases with most impact as it compiles major features that are essential to 5G. The domain of application of the research activities of research cluster 1 is directed towards TC2, with exception of TeC2 which focuses on TC1 "Virtual reality office", while research cluster 2 targets a wider variety of test cases. As a first step towards developing a global solution to test case 2 and evaluating the different TeC in a common framework, common baseline simulation assumptions have been determined and are described in Appendix B, section 8.3. In future deliverables, the partners targeting test case 2 will rely on those common simulation assumptions.

4.2 Research Cluster 1: Infrastructure-based relaying and wireless backhauling

4.2.1 Introduction

This research cluster focuses on a network densification exploiting spectrally efficient infrastructure-based relaying and wireless backhauling, e.g. as an enabler for densification and mmW spectrum utilization. The approaches include multi-flow coordination-based on relaying and network coding, interference-aware routing and efficient resource allocation in multi-hop wireless backhaul networks, buffer-aided relaying, and efficient non-orthogonal transmission techniques.

The main challenges of this research cluster are to recover the spectral efficiency loss caused by half-duplex transmissions in relay-based and/or wireless backhaul networks and to accommodate a large amount of users with very high data rates by spatial reuse in UDNs.

According to these challenges, the goal is to exploit the relays to enhance the overall spectral efficiency by allowing multiple communication flows to co-exist in such a way that the interference between them can be managed efficiently.

- All the TeCs except for TeC 2 primarily consider TC 2 - Dense urban information society as the most relevant common TC. TeC 2 is more aligned to TC 1 - Virtual reality office although it is also possible to be applied to TC 2. In addition, TeC 4 can be applied for TC 3/4/9 as well.

The main ideas of TeCs in this research cluster are summarized in Table 4.1.

Table 4.1: T3.3 RC1 Technology Components

TeC #	Short Title	Short description
TeC 1	Coordinated multi-flow transmission for wireless backhaul.	Devise transmission schemes for cellular networks consisting of BS, RSs and MSs, where RSs are used as a means to enable an efficient wireless backhaul solution.
TeC 2	IAR and RA in a mmW UDN	To enhance spectrum efficiency, sub-optimal low-complexity Interference Aware Routing (IAR) and resource allocation (RA) schemes are provided, taking interference into account for several multi-hop flows.
TeC 3	Virtual Full-Duplex Buffer-aided Relaying (VFD-BR)	To overcome multiplexing loss of half duplex relaying, concurrent transmissions of the source and a relay are allowed with interference cancellation exploiting more than two relays with buffer and multiple antennas.
TeC 4	Distributed Coding for the Multiple Access Multiple Relay Channel (MAMRC)	To reach high spectrum efficiency, non-orthogonal access techniques combined with wireless network coding are considered in a cooperative communication setting.
TeC 5	IDMA-based bi-directional relaying	The impact of Interleave Division Multiple Access (IDMA) is analysed in combination with network coding to identify efficient strategies regarding MAC/BC structuring, resource allocation and channel coding for bi-directional communication.

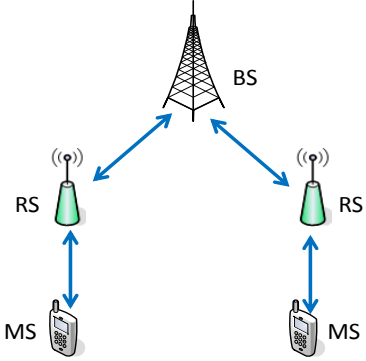
The potential benefits that can be achieved with TeC 1-5 are briefly summarized as follows:

- TeC 1: Increase of spectral efficiency such that wired backhauling can be replaced by wireless relaying keeping the same performance.
- TeC 2: Increase of system and user throughputs to provide very high data rates for large amount of users in mmW indoor environments.
- TeC 3: Increase of spectral efficiency of edge users supported by relays with one-way traffic (DL or UL) in multiple buffer-equipped relay networks.
- TeC 4: Increase of spectral efficiency, system capacity, and coverage in multi-relay (UL) multiple access networks. Increase of reliability for fixed rate transmission.
- TeC 5: Increase of spectral efficiency/user throughput and accommodation of a very high density of users operating in wide bands with two-way traffic (DL and UL).

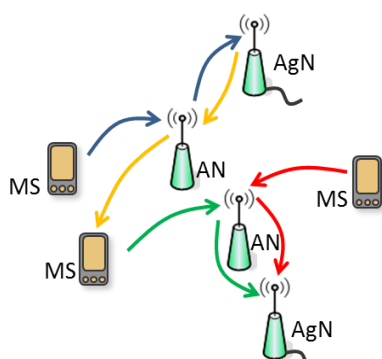
4.2.2 Overview of preliminary results

This section provides an overview of the TeCs under study in Task 3.3 Research Cluster 1, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in section 9.3.

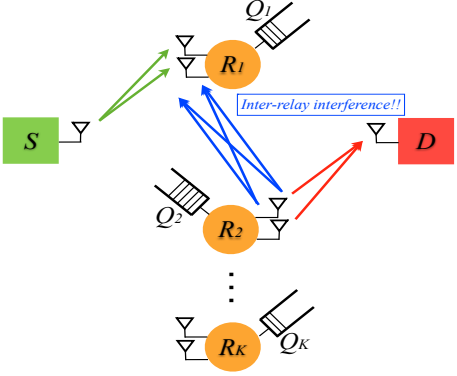
The structure and meaning of the different fields in the table have been described in section 2.2.2.

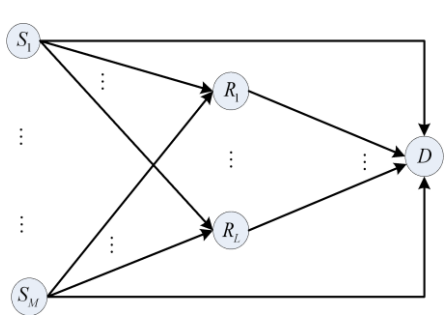
T3.3 TeC.01 - Coordinated multi-flow transmission for wireless backhaul	
 <p>Antipodal relays, not interfering with each other. One terminal is connected to one relay and has a two-way traffic with the BS.</p>	<p style="text-align: center;">Main Idea</p> <p>$2N$ flows, N downlink and N uplink, for N relayed users, are served jointly through two transmission phases. In the first phase, the BS broadcasts signals for all terminals to their relays, while each terminal transmits to its relay. In the second phase, each relay broadcasts to its terminal and the BS. Side information at the BS and terminals is used. By coupling all flows, the total service time is decreased or, equivalently, the data rates of all nodes are increased.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> Spectral Efficiency: Expected gain 50-100%
Performance Evaluation Approach	Analytical and Simulation-based
Simulation Type	Link level, Multi-Link level
Dynamic Class	Static model
System Model Considered	RC-baseline
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> Model of environment: Not Applicable Spectrum assumption: Not Applicable Propagation model: Simplified propagation model User/Device deployment model: Not Applicable Traffic model: Full buffer
Considered Legacy Solution	LTE Release 11

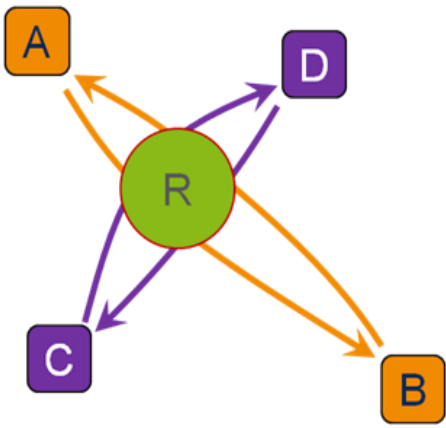
T3.3 TeC.02 – Interference aware routing and resource allocation in a millimetre-wave ultra dense network

	<p>Main Idea</p> <p>To provide high data rate coverage in mmW indoor environments, a denser network than fixed backhaul can provide is considered. In order to enhance spectrum efficiency, wireless backhaul and access share spectrum and nodes. The purpose is to develop practical low-complexity routing and resource allocation schemes that take interference into account for several multi-hop flows in the mesh of access nodes (ANs), to one or several fibre connected access nodes doubling as aggregation nodes (AgN).</p>
---	---

<p>KPIs considered and Expected gain</p>	<p>(Relative gains % Not Available yet, absolute values only)</p> <ul style="list-style-type: none"> • System Throughput: 3–25bps/Hz depending on deployment scenario • Average User Throughput: ~70Mbps–1.5Gbps @ 184MHz bandwidth depending on load and number of AgN's • Average User Delay, 75–150µs depending on number of AgN's
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>Simplified system level evaluation</p>
<p>Dynamic Class</p>	<p>Semi-static model</p>
<p>System Model Considered</p>	<p>RC-baseline/Other (TC1 inspired indoor mmW scenario)</p>
<p>Deviation compared to RC Baseline</p>	<p>Significant but quite similar to TC1 suggestion</p> <ul style="list-style-type: none"> • Model of environment: Six room office + corridor floor plan, total size 25x30m • Spectrum assumptions: 60GHz, 184,32MHz BW • Propagation model: Ray-tracing up to 2 reflections with loss 5.6dB + fading component from random orientation point sources • Device distribution: 1 ceiling AN per room + 4 AN in corridor (3 in ceiling + 1 AgN on wall), 1,2, 4 AN in corridor or all 10 acting as wired AgN • User distribution: Uniform grid-based random user positions according to load • Traffic model: Full buffer pipelined traffic
<p>Considered Legacy Solution</p>	<p>Not applicable</p>

T3.3 TeC.03 – Virtual full-duplex buffer-aided relaying	
	<p style="text-align: center;">Main Idea</p> <p>Buffer-aided relaying enables virtual full-duplex communication in a network where two relays allow concurrent transmissions with inter-relay interference cancellation. One relay receives the information from the source while the other forwards the information to the destination. The idea is to find the best relay-pair for Source-Relay and Relay-Destination links with beamforming design to mitigate inter-relay interference at both transmitting and receiving relays.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> Spectral Efficiency: Expected gain 45–100% compared to state-of-the-art half duplex relaying scheme, 30–400% compared to conventional spatial full duplex MMRS scheme without inter-relay interference consideration
Performance Evaluation Approach	Semi-analytic and Simulation-based
Simulation Type	Simplified system level evaluation
Dynamic Class	Static model
System Model Considered	RC-baseline
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> Model of environment: N/A Spectrum assumption: N/A Propagation model: i.i.d. Rayleigh block fading for all the links User/Device deployment model: N/A Traffic model: Full buffer
Considered Legacy Solution	State-of-the-art half duplex relaying scheme or conventional spatial full duplex MMRS scheme

T3.3 TeC.04 - Distributed coding for the multiple access multiple relay channel	
	<p style="text-align: center;">Main Idea</p> <p>To reach high spectrum efficiency, non-orthogonal access techniques combined with wireless network coding are considered in a cooperative communication setting. The relaying function denoted Selective Decode and Forward (SDF) is applied at the relay, i.e. the relay gathers the messages that it can decode free of errors and forwards a deterministic function of the sources' messages.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Average BLER (outage) with respect to SNR links and average data rate (ϵ-capacity) with respect to SNR links for a target BLER of $\epsilon = 10\%$ • Gain in spectral efficiency or better BLER (reliability) for the same transmitted power • 10dB gain for BLER = 0.01 by using 2 relays for Rayleigh fading links
Performance Evaluation Approach	Analytical and Simulation-based
Simulation Type	Multi-link level
Dynamic Class	Static model
System Model Considered	RC-baseline
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> • Model of environment: N/A • Spectrum assumption: N/A • Propagation model: simplified MIMO block fading with AWGN channel models • User/Device deployment model: N/A • Traffic model: Full buffer
Considered Legacy Solution	Multiple access channel without relays

T3.3 TeC.05 – Bi-directional relaying with non-orthogonal multiple access	
	<p style="text-align: center;">Main Idea</p> <p>This work focuses on bi-directional relaying with multiple data flows and multiple communication pairs employing Interleave Division Multiple Access (IDMA) as non-orthogonal multiple access scheme. The application of IDMA offers a high degree of flexibility and allows for the combination with known approaches, such as network coding, in order to create efficient combinations of the multiple access (MAC) and broadcast (BC) phases. The impact of IDMA is analysed in combination with network coding to identify efficient strategies regarding MAC/BC structuring, resource allocation and channel coding for bi-directional communication.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> Spectral Efficiency/User Throughput: Expected gain 43% compared to non-optimized IDMA system
Performance Evaluation Approach	Semi-analytical and Simulation-based
Simulation Type	Link level, Multi-link level
Dynamic Class	Static model
System Model Considered	RC-baseline
Deviation compared to RC Baseline	Minor: <ul style="list-style-type: none"> Model of environment: N/A Spectrum assumption: N/A Propagation model: Simplified propagation model User/Device deployment model: Simplified deployment model Traffic model: Full buffer
Considered Legacy Solution	non-optimized IDMA system

4.2.3 TeC complementarity analysis

Also in this section complementarity is defined as follows: TeCx complements TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy. Note that complementarity is not symmetric as TeCy does not necessarily enhance the performance of TeCx. Table 4.2 summarized the results: in this table, the TeCs listed in the green column are assessed as complementary or non-complementary to the TeC listed in the blue row. Complementary is analysed in more details on a TeC basis:

- TeC1: this TeC provides building blocks for wireless backhaul based on wireless network coding. The transmission techniques based on wireless network coding can be used to further increase the spectral efficiency of the methods developed in TeC2.
- TeC2: the algorithms developed in TeC2 are specific to multi-hop mesh network. Therefore, their applicability to other TeCs is limited as the other TeCs consider one-hop networks.
- TeC3: buffer-aided relaying (not specific to full duplex) can be exploited by all TeCs to enhance spectral efficiency in the presence of multiple relays or multiple users.
- TeC4: the solution developed in TeC4 can be part of a global relay-based solution. However, it cannot be considered as a complement to another TeC.
- TeC5: TeC5 develops solutions for non-orthogonal access of bi-directional traffic. Non-orthogonal access can be exploited by TeC1 as a practical coding scheme.

Table 4.2. T3.3 RC1 Overview of the TeC complementarity analysis

TeCx Complements TeCy	TeC 1 Multi-Flow Wireless Backhaul	TeC 2 Routing for indoor mm- wave	TeC 3 Buffer-Aided Relaying	TeC 4 Multiple Access Multiple Relay Channel	TeC 5 Bi-Directional Relaying Non- Orthogonal MA
TeC 1	-	Yes	No	No	No
TeC 2	No	-	No	No	No
TeC 3	Yes	Yes	-	Yes	Yes
TeC 4	No	No	No	-	No
TeC 5	Yes	Yes	No	No	-

4.3 Research Cluster 2: Infrastructure-less/infrastructure-assisted D2D and mobile relays

4.3.1 Introduction

This RC is focused on the study of infrastructure-assisted/infrastructure-less D2D communication and mobile relays. With respect to the D2D communication, this RC addresses improvements to achievable data rates both when a large number of users within a small area are trying to access services and when users act as a relay. The topic of direct communication between devices is addressed in various ways. First, TeC 6 proposes relay assisted D2D communication with optimum precoding and decoding when all nodes have multiple antennas together with switching to a direct D2D communication when it is beneficial in terms of data rate. The use of a relay provides range extension to D2D communication with less transmit

power. Cooperative D2D communication is considered by TeC 7. In this scheme, cooperation between cellular links and D2D communication links increase the spectral efficiency, the cell throughput, the number of connected devices within the cell, and the cell coverage. D2D relaying together with practical design of a distributed multi-functional MIMO system is addressed in TeC 8. The proposed solution increases spectral efficiency and cell border throughput in the downlink. Enhancement for the uplink transmission can be achieved by using TeC 9 where by using D2D communication and cooperating with each other, less energy is required to send the same amount of data of each active vehicular UE (VUE) in the cooperative transmission than the individual VUE-to-BS communications. In D3.1 [METIS31] a study of using moving relay nodes (MRN) to enhance the vehicular user equipment (VUE) communication was presented as TeC 9. Finally, in TeC 10 the two-phase two-way relaying scheme is investigated. In the proposed solution for the broadcast phase of two-way relaying, throughput is increased by MU-MIMO like precoding techniques performed by the relay station and interference is suppressed by interference cancellation at the receiver side. The delay is reduced as well by applying only two phases. The main ideas of the TeCs in this research cluster are summarized in Table 4.3.

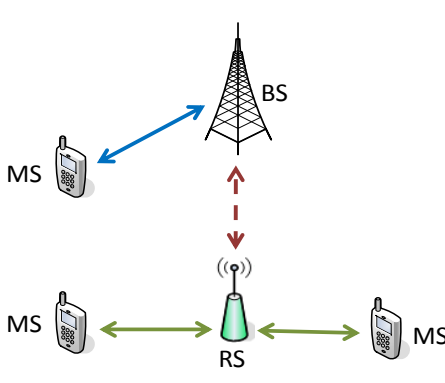
Table 4.3: T3.3 RC2 Technology Components

TeC #	Short Title	Short description
TeC 6	MIMO PLNC to expand D2D coverage	A relay assisted D2D communication is considered with all nodes having multiple antennas, where the relay performs physical layer network coding (PLNC). The D2D transmission uses the same frequency spectrum as cellular communication.
TeC 7	Cooperative D2D Communications (CD2DC)	The main objective behind the proposed scheme is to allow cooperation between cellular links and direct device-to-device communication links to increase the spectral efficiency, the cell throughput, the number of connected devices within the cell, and the cell coverage.
TeC 8	Open-loop D2D relaying.	This work extends the concept of multi-functional MIMO transmission to implement distributed space-time coding in networks with UE relays of limited capabilities.
TeC 9	D2D communications to Enhance VUE uplink	By using D2D communication and cooperating with each other, less energy is required to send the same amount of data of each active VUE in the cooperative transmission than the individual VUE-to-BS communications.
TeC 10	NC and MIMO in TDD system with relaying	In this TeC the two-phase two-way relaying scheme is investigated. The main focus in this contribution is put on the second phase where two different schemes are compared: network coding and MU-MIMO.

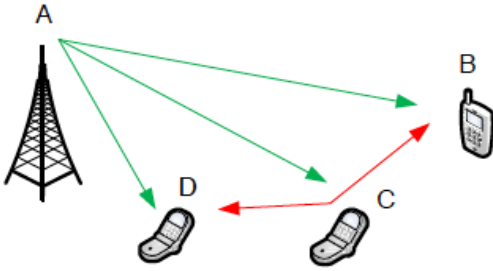
4.3.2 Overview of preliminary results

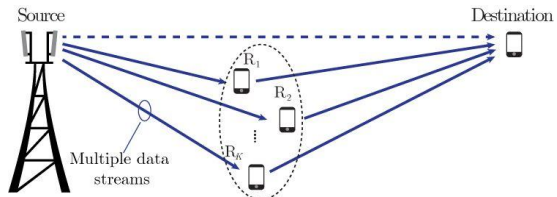
This section provides an overview of the TeCs under study in Task 3.3 Research Cluster 2, collected in a series of tables that highlight the expected gains that can be provided by each TeC and the performance evaluation approach that has been followed in this first phase of the METIS project. More detailed results are also available in Appendix C, section 9.3.

The structure and meaning of the different fields in the table have been described in section 2.2.2.

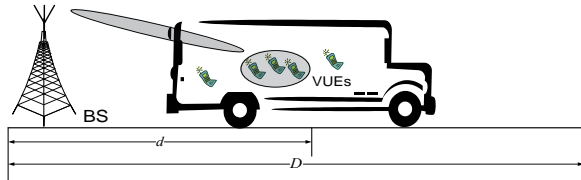
T3.3 TeC.06 - MIMO physical layer network coding based underlay D2D communication	
	<p style="text-align: center;">Main Idea</p> <p>The main idea is to develop multiple antenna techniques at the transmitting or receiving nodes to ensure coexistence of D2D and cellular communications in the same spectrum. The relay node uses physical layer network coding to deliver high spectrum efficiency.</p> <p>During the first transmission phase, the two devices and the BS transmit simultaneously. To suppress the mutual interference caused by those simultaneous transmissions, MMSE pre/decoders are used at all nodes. During a second transmission phase, the relay broadcasts the network coded messages while the direct user transmits to the BS. MMSE pre/decoders are used at all nodes to suppress the interference.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> • Coverage enhancement of D2D pair to be evaluated • BER enhancement by the transmit mode selection to be evaluated
Performance Evaluation Approach	Analytical and Simulation-based
Simulation Type	Link level, Multi-link level
Dynamic Class	Static model
System Model Considered	Single-cell, underlay spectrum access with interferences are considered with frequency flat fading.
Deviation compared to RC Baseline	Minor
Considered Legacy Solution	Not Applicable

T3.3 TeC.07 - Cooperative D2D Communications

 <p>Links AB and CD share the same radio resource via cooperation</p>	<p>Main Idea</p> <p>D2D communication is achieved through cooperation where the interested device relays information from the base station to a mobile user and at the same time gets the opportunity to communicate directly with another device. Hence, by acting as a relay the mobile device can achieve D2D communication with no extra resources. Orthogonal spectrum splitting and superposition coding is considered in the cooperation process.</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • User data rate: Cellular rate unchanged, D2D rate increases in a best effort manner. • Cell throughput: under investigation • Active links/radio resource/cell: an increase by 100%
<p>Performance Evaluation Approach</p>	<p>Analytical & Simulation-based</p>
<p>Simulation Type</p>	<p>System level evaluation</p>
<p>Dynamic Class</p>	<p>Semi-static model</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>Some:</p> <ul style="list-style-type: none"> • Model of environment: Urban Macro area • Spectrum Assumptions: 2 GHz • Propagation model: Based on model in [XH10] • Deployment model: Single cell (Hexagonal) • User/Device Distribution: Uniform • Traffic model: Full Buffer
<p>Considered Legacy Solution</p>	<p>Adapted LTE Release 11</p>

T3.3 TeC.08 - Open-loop techniques in a network with D2D relaying	
 <p>Communication from a multi-antenna base station to a multi-antenna destination user, assisted by multi-antenna users acting as relay nodes.</p>	<p style="text-align: center;">Main Idea</p> <p>Multiple streams intended to a possibly out-of-reach user are relayed by a group of UE relays. All the nodes are equipped with multiple antennas. The work focuses on practical limitation linked to the use of user terminal as relays: a) no cooperation among UEs, b) CSI unavailability at the UE inducing open-loop transmission for D2D relaying, c) limited computation capabilities and d) limited number of antennas.</p>
KPIs considered and Expected gain	<ul style="list-style-type: none"> BER/Rate, Expected Gain of 1-6 dB in the BER vs transmitted power curve
Performance Evaluation Approach	Simulation-based
Simulation Type	Link level
Dynamic Class	Static model
System Model Considered	Other
Deviation compared to RC Baseline	Use of a simplified system model. We assume a transmission through block-fading Rayleigh channels, containing Gaussian i.i.d. elements with zero mean and unit variance.
Considered Legacy Solution	LTE-MIMO 2x2, Open-loop transmit diversity through space-frequency block coding, Open-loop beamforming

T3.3 TeC.09 - Uplink enhancement of vehicular users by using D2D communications



Main Idea

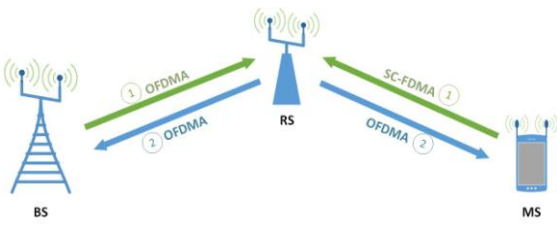
There are n VUEs in a bus. We assume m out of n VUEs are active and need to send data to the BS.

By using D2D communication, the m VUEs can exchange data with each other, and cooperate to communicate with the BS.

In this way, less energy is required to send the same amount of data of each active VUE in the cooperative transmission than the individual VUE-to-BS communications.

KPIs considered and Expected gain	<ul style="list-style-type: none"> TX energy spent on per information bit [J/bit] under evaluation
Performance Evaluation Approach	Simulation-based
Simulation Type	System level evaluation
Dynamic Class	Static model
System Model Considered	We consider a single cell, noise limited system with frequency flat fading.
Deviation compared to RC Baseline	Not Applicable (This study is only a proof of concept.)
Considered Legacy Solution	Not Applicable

T3.3 TeC.10 – Combining physical layer network coding and MIMO for TDD wireless systems with relaying

 <p>One mobile station and one base station with two-way traffic through a relay with multiple antennas using OFDMA in downlink and SC-FDMA in uplink.</p>	<p>Main Idea</p> <p>This work considers the joint application of network coding and MIMO transmission with the aim at improving throughput or reliability and robustness in a two-way relaying scenario. Multiple antennas at the relay station are used to separate data blocks received on the same radio resources by utilizing the spatial dimension. After the decoding of the separated data blocks, network coding is applied and the re-encoded data block is broadcasted. Comparison to a scheme with MU-MIMO as an alternative to network coding is made as well.</p>
<p>KPIs considered and Expected gain</p>	<ul style="list-style-type: none"> • User throughput: compared to classical 2-way relaying scheme increases by 100%, and compared to network layer NC increases by 50%. • Air Delay: compared to classical 2-way relaying scheme decreases by 50% (from 4 to 2 slots) compared to network layer NC decreases by 33.3% (from 3 to 2 slots)
<p>Performance Evaluation Approach</p>	<p>Simulation-based</p>
<p>Simulation Type</p>	<p>Multi-link level evaluation</p>
<p>Dynamic Class</p>	<p>Not Applicable</p>
<p>System Model Considered</p>	<p>Other</p>
<p>Deviation compared to RC Baseline</p>	<p>At the moment we consider a simplified system model with one base station, one relay station and one mobile station. We use channel models such as EPA, ETU and EVA. In a later phase we will perform system-level simulations.</p>
<p>Considered Legacy Solution</p>	<p>The existing 3GPP LTE system (Rel-10/11) with a reasonable density of access points (eNB, Relay, HeNB/WiFi) and certain specified RRM schemes (e.g., proportional fair scheduling, partial frequency reuse, eICIC) can be considered as legacy networks.</p>

4.3.3 TeC complementarity analysis

Complementarity is defined as follows. TeCx complements TeCy if the techniques developed in TeCx can be used in TeCy to further enhance the performance of TeCy. Note that complementarity is not symmetric as TeCy does not necessarily enhance the performance of TeCx. Table 4.4 summarized the results: in this table, the TeCs listed in the green column are assessed as complementary or non-complementary to the TeC listed in the blue row. Complementarity is analysed in more details on a TeC basis:

- TeC6: This TeC develops a solution based on multiple antennas to ensure the coexistence of D2D (direct or through relay) communications and cellular communications. This solution can be used in other TeCs where the use of D2D communications is extended as an underlay network, i.e. for TeC7, TeC10.
- TeC7: The solution developed is based on a specific scenario where a device serves both as a relay and as the source of a D2D transmission. Therefore, it is not seen as a complement to any TeC. Actually, TeC7 takes the perspective of cooperation between the cellular and the D2D communications while TeC6 considers them as competitive.
- TeC8: Similarly to TeC7, TeC8 is not seen as a complement to any TeC.
- TeC9: TeC9 develops a solution for distributed MIMO from multiple devices located in a vehicle. This TeC does not complement any other TeC.
- TeC10: TeC10 considers multiple antenna based communication methods for two-way relaying. Those methods can also be applied in the context of TeC6 which also considers D2D through a relay.

Table 4.4. T3.3 RC2 Overview of the TeC complementarity analysis

TeCx Complements TeCy	TeC 6 Underlay D2D with physical layer network coding	TeC 7 Cooperative D2D Communications	TeC 8 Network with D2D relaying	TeC 9 Vehicular user D2D to enable distributed MIMO for Uplink	TeC 10 Combining Physical Layer Network Coding and MIMO for TDD wireless systems with relaying
TeC 6	-	Yes	No	No	Yes
TeC 7	No	-	No	No	No
TeC 8	No	No	-	No	No
TeC 9	No	No	No	-	No
TeC 10	Yes	No	No	No	-

4.4 Most promising concepts from Task T3.3

Task T3.3 has identified “**In band backhaul and access**” as the most promising technology to be incorporated in the overall system concept of METIS. The activities of T3.3 can be divided into two main areas:

- **Heterogeneous network at lower frequencies (< 10GHz)**

- The principles of **wireless network coding** are applied to cellular architectures with small cells in order to regain the loss due to half duplex relaying (performed by the small cell base stations). The target is to obtain a performance that is close to a wired backhaul solution taking into account the interference potentially created by the wireless backhaul transmission (TeC1). The spectral efficiency of those new transmission methods can be further enhanced using the following techniques developed in TeC5 and TeC3.
- Practical **multiple access schemes** used in conjunction with wireless network coding is developed in TeC5.
- **Buffer-aided relaying** is investigated in TeC3 for the specific purpose of mimicking full-duplex relaying. However, the concept of buffer-aided relaying can be generalized to improve the spectral efficiency of the methods developed in TeC1.
- **Indoor dense mesh network at mm-waves** (TeC2). Communications at mm-wave frequencies are of primary interest in METIS concept. TeC2 puts forward a practical deployment of an indoor dense mesh network a mm-waves, with a realistic ray tracing based channel modelling and specific placement of the access points. The wireless backhaul and access share the same spectrum. The goal consists of low-complexity routing and resource allocation schemes applicable to more general topologies of wirelessly connected access nodes. The methods developed for cellular architectures (TeC1, TeC5, TeC3) are generic enough to be applicable to mm-waves. Therefore, those methods can enhance critical/limiting bottlenecks in the scenarios considered in TeC2 if 2-way traffic is considered along with wireless network coding.

4.5 Interactions between T3.3 and other METIS WPs

Table 4.5 summarizes the expected level of interactions between Task 3.3 and the other METIS WPs.

WP1: the expected interaction level is **small**. WP1 is expected to provide more realistic channel models, especially for D2D communications. The most common assumptions within T3.3 is a simple Rayleigh fading model and there is a definite need to upgrade the channel models to more realistic ones.

WP2: the expected interaction level is **small**. It is expected that new waveforms provided in WP2 may modify the performance of the proposed techniques in T3.3. Furthermore, the D2D research activities within T3.3 might benefit from the developed solutions in WP2.

WP4: the expected interaction level is **moderate**. Interference management schemes developed in WP4 are expected to be useful to the majority of the TeCs. For TeCs involving D2D, a close alignment and good interaction with WP4 is needed to allow the coexistence of D2D communication with the cellular network.

WP5: the expected interaction level is **small**. The occupied spectrum and hence frequency range is expected to impact the performance results due to the difference in channel characteristics across frequency bands. Interaction with WP5 is required to determine the right spectrum bands used in a realistic system level evaluation.

WP6: the expected interaction level is **small**. WP6 provides simulation guidelines and is the main source to determine a common simulation baseline for all TeC with the purpose of more realistic performance results but also of a comparison between solutions within T3.3

Table 4.5: Interactions between T3.3 and METIS WPs

	WP1	WP2	WP4	WP5	WP6
Task 3.3	Small	Small	Moderate	None/Small	Small



4.6 Conclusion

This section summarized the preliminary results for each technology component composing the multi-hop communications and wireless network coding task. The next phase of the project focuses on consolidating those results where 2 objectives will be pursued: first, the simulations will be aligned to achieve an evaluation matched to the test cases and second, synergies among TeCs will be exploited.

5 Conclusion and future work

This document has shown the current assessment and evaluation of the technologies investigated in WP3. The simulation alignment effort is detailed in Appendix B section 8, and the results presented here reflect the first investigations taking this alignment into account. The main reason for this first alignment on scenarios and simulation parameters had the aim of supporting the identification of some technologies that have high potential for 5G systems. Some of those approaches regarding Massive MIMO, advanced interference coordination and multihop communications/wireless network coding have been described here.

Moreover, a TeC complementary analysis was performed, where possible interactions between TeCs have the potential to further boost the current performance results and also to further increase the level of innovation in WP3. Finally, details on the simulation alignment, the impact on TCs and on the TeCs results can be found in the Appendix for the interested reader.

It was here reassured and reconfirmed that the most recent results corroborate that WP3 is very well positioned. Indeed, WP3 is showing a good mix of medium and long term impact, and is providing valuable inputs for the development of 5G systems.

In Task 3.1, individual contributions have shown the performance of Massive MIMO in practical scenarios. RC1, for example, has presented the results on Massive MIMO for mm-waves and high mobility, while RC2 focused on obtaining more realistic results in heterogeneous multicellular systems and using simplified processing techniques. T3.1 has identified that Massive MIMO as in-band backhaul is a significant enabler of ultra dense networks and an essential feature for the goal of capacity increase in 5G systems. Another high potential approach that was identified was Massive MIMO for access. Results such as bit rates of 20 Gbps, are encouraging and exemplify the potential of the technique.

The results in task 3.2 have shown that cooperation approaches allow improvements to the average spectral efficiency and cell-edge throughput of the system, thus also increasing the overall fairness of the system. Two main approaches were identified as very promising ones for 5G systems. Using UEs with advanced capabilities alleviates the coordination complexity at the network side and reduces the feedback requirements. Moreover the combination of Massive MIMO and CoMP solves issues of traditional interference coordination schemes, such as rank deficiency and limited indoor coverage. Other techniques, such as Interference Alignment, are under investigation to reach full maturity when applied to real systems.

Task 3.3 has identified in-band backhaul and access as its most promising technology. Indeed, many innovative techniques are investigated in T3.3 that allows in-band backhauling and access. Two main paths are followed. The first one focuses on heterogeneous network at lower frequencies (<10GHz). There, principles such as network coding, proper access schemes and buffer-aided relaying provide sound techniques for the heterogeneous approaches. Additionally, mesh networks at mm-waves are also considered for dense indoor scenarios.

WP3 is now further refining its results and enhancing the potential interactions between different approaches. It is to expect that new very promising techniques will be identified in the near future as a consequence of the efforts for maturing the results of some TeCs.



6 References

[3GPP12-36828] 3GPP TR 36.828, "Further Enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) Interference Management and Traffic Adaptation (Release 11)", Jun. 12.

[AP12] S. Abdallah and I. Psaromiligkos, "Widely linear versus conventional subspace-based estimation of SIMO flat-fading channels: Mean squared error analysis," *IEEE Trans. Signal Process.*, vol. 60, no. 3, pp. 1307-1318, Mar. 2012.

[ARTIST51] ARTIST4G consortium, "ARTIST4G D5.1 – Scenarios, Key Performance Indicators and Evaluation Methodology for Advanced Cellular Systems", project report, May 2010, <https://ict-artist4g.eu>.

[BDJT12] K. Borner, J. Dommel, S. Jaeckel, and L. Thiele, "On the requirements for quasi-deterministic radio channel models for heterogeneous networks," In *Signals, Systems, and Electronics (ISSSE)*, 2012 International Symposium on, pp. 1–5, Oct. 2012.

[DY10] Dahrouj H. & Yu W. (2010) Coordinated beamforming for the multicell multi-antenna wireless system. *IEEE Transactions on Wireless Communications* 9, pp. 1748–1759.

[GCJ08] K. S. Gomadam, V. R. Cadambe and S. A. Jafar, "Approaching the Capacity of Wireless Networks through Distributed Interference Alignment," *Proceedings of IEEE GLOBECOM*, New Orleans, LA, Dec. 2008.

[JBTJ12] S. Jaeckel, K. Börner, L. Thiele, and V. Jungnickel, "A Geometric Polarization Rotation Model for the 3-D Spatial Channel Model," *Antennas and Propagation, IEEE Transactions on*, 60(12): pp. 5966–5977, 2012.

[LHDA10] S. Lakshminarayana, J. Hoydis, M. Debbah, M. Assaad, "Asymptotic analysis of distributed multi-cell beamforming," *IEEE PIMRC 2010*, Istanbul, Turkey, pp. 2105-2110, 26-29 September 2010.

[LSY13a] Y. Lejosne, D. Slock, and Y. Yuan-Wu, "Finite Rate of Innovation Channel Models and DoF of MIMO Multi-User Systems with Delayed CSIT Feedback," in *Proc. ITA*, San Diego, CA, USA, Feb. 2013.

[MC13a] J. F. Monserrat and Jordi Calabuig, "Software implementation (Matlab) of PS1 and PS2," 2013. URL: <https://www.metis2020.com/documents/simulations/>.

[MC13b] J. F. Monserrat and Jordi Calabuig, "Software implementation (Matlab) of PS3 and PS4," 2013. URL: <https://www.metis2020.com/documents/simulations/>.

[METIS11] METIS consortium, "D1.1 – Scenarios, requirements and KPIs for 5G mobile and wireless system," project report, Apr. 2013.

[METIS22] METIS consortium, "D2.2 – Novel radio link concepts and state of the art analysis," project report, Oct. 2013

[METIS31] METIS consortium, "D3.1 – Positioning of multi-node/multi-antenna technologies," project report, Jul. 2013.

[METIS61] METIS consortium, "D6.1 – Simulation guidelines," project report, Oct. 2013.

[NL12] H. Q. Ngo and E. Larsson, "EVD-based channel estimation in multicell multiuser MIMO systems with very large antenna arrays," in *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, pp. 3249-3252, Mar. 2012.

[PHH13] D.T. Phan Huy, M. H elard, "Large MISO Beamforming For High Speed Vehicles Using Separate Receive & Training Antennas," *IEEE International Symposium on Wireless Vehicular Communications (WiVEC)*, Dresden, Germany, 2-3 June 2013.



[TPK11] A. Tölli, H. Pennanen, and P. Komulainen, "Decentralized Minimum Power Multi-cell Beamforming with Limited Backhaul Signalling," *IEEE Trans. on Wireless Comm.*, vol. 10, no. 2, pp. 570 - 580, February 2011.

[WCMD12] S. Wagner, R. Couillet, M. Debbah, D. T. M. Slock, "Large System Analysis of Linear Precoding in Correlated MISO Broadcast Channels under Limited Feedback," *IEEE Trans. Inf. Theory*, vol. 58, no. 7, pp. 4509 - 4537, Jul. 2012.

[XH10] H. Xing and S. Hakola, "The investigation of power control schemes for a device-to-device communication integrated into OFDMA cellular system," in *Proc. IEEE PIMRC '2010*, Istanbul, Turkey, September 2010, pp. 1775–1780.

[YTJ+08] C. Yetis, G. Tiangao, S. Jafar, and A. Kayran, "Approaching the capacity of wireless networks through distributed interference alignment," in *Proc. IEEE Global Telecommunications Conference, 2008. GLOBECOM 2008*, New Orleans, LO, Dec. 2008.



7 Appendix A: Impact on Test Cases

The following tables report the impact that WP3 innovations can have on the Test Cases defined in METIS [METIS11]. For each impacted Test Case certain main objectives are listed, followed by the Technology components that can help in achieving that objective, detailing the specific challenge that the TeC can solve, a brief description of the proposed solution, specific requirements that are needed by the solution, and an estimate of the expected gain that can be offered.

Test Case #1 - Virtual reality office			
Increase Spectral Efficiency			
Specific Challenge			Increase spectral efficiency and relax feedback and backhauling requirements
T3.2 TeC 2	<i>Solution</i>		Reduce the feedback needed for the CoMP scheme without degradation of the total throughput, balancing the period of updating the CSI and the codebook size for the feedback.
	<i>Requirements</i>		Not high speed UEs
	<i>Expected Gain</i>		Observed feedback reduction up to 76% for 15km/h and the used codebook size. Could be even larger for the low speed users considered in this TC.
Specific Challenge			Very high data rates for large amount of users
T3.3 TeC 2	<i>Solution</i>		This TeC contributes to TC1 by addressing how to share resources of dense access points also for wireless backhauling to enable sufficient densification to provide high data rate coverage in mmW.
	<i>Requirements</i>		Centralized node responsible for routing/resource allocation in the UDN, Stationary users with reasonably stable traffic demand as link quality needs to be communicated to central node, Large bandwidths of spectrum available in mmW area
	<i>Expected Gain</i>		Assuming 2GHz BW and for a smallest deployment in terms of AN and AgN's: <ul style="list-style-type: none"> • Average data rate, 0.5Gbps UL/DL • Traffic volume per area, 100Mbps/m² UL/DL • Experienced user data rate, 95% above 1Gbps, 20% above 5Gbps



Test Case #2 - Dense urban information society			
Increase Spectral Efficiency			
Specific Challenge		Increase spectral efficiency, capacity and coverage.	
	T3.1 TeC 5	<i>Solution</i>	Model based channel prediction provides high quality channel prediction in combination with strong feedback reduction.
		<i>Requirements</i>	Requires novel UE and eNB signal processing for generating, transmitting and receiving of new CSI feedback information.
		<i>Expected Gain</i>	Spectral efficiency, Expected Gain >100% (as known for perfect CSI from ARTIST4G evaluation).
	T3.2 TeC 4	<i>Solution</i>	The proposed user selection algorithms are designed to exploit the user diversity gains to align and cancel the MUI and ICI.
		<i>Requirements</i>	Channel and Interference information at the BS.
		<i>Expected Gain</i>	System Spectral efficiency: average gain from 20% to 45%
	T3.2 TeC 7	<i>Solution</i>	Design CoMP with dynamic clustering, better exploiting multiple antennas at the UE to reduce ICI and increase spectral efficiency.
		<i>Requirements</i>	Low-latency and high-throughput backhauling for CoMP-JP. Low-mobility scenarios for good quality CSI at the BSs.
		<i>Expected Gain</i>	Cell throughput: average gain from 10% to 20% User throughput: 5th perc. gain from 30% to 50% Spectral efficiency: average gain from 10% to 20%
	T3.2 TeC 10	<i>Solution</i>	Assume downlink JT with UEs equipped with co-channel interference suppression capabilities and allowed to choose the desired cluster of BSs. Feedback delays are mitigated by linear adaptive channel prediction.
		<i>Requirements</i>	Low mobility users, full CSIT, feedback outdate can be compensated.
		<i>Expected Gain</i>	Increase cell data rate, user data rate, better user outage probability.
	T3.2 TeC 13	<i>Solution</i>	Extend IMF-A framework by higher number of TX-antennas per cell and by adding increasing number of small cells
		<i>Requirements</i>	Requires support of massive MIMO arrays and suitable interference concept for inband integration of small cells into wide area network
		<i>Expected Gain</i>	Spectral efficiency, Expected Gain >100% to factor of 10
	T3.2 TeC 14	<i>Solution</i>	Clustering of users and coordinating resource allocation to mitigate interference.
		<i>Requirements</i>	UE mobility limited Hotspots mobility limited Multiple antennas available at the RN, BS and UE
		<i>Expected Gain</i>	Cell throughput: Under investigation User throughput: Under investigation Spectral efficiency: Under investigation
	T3.3 TeC 4	<i>Solution</i>	Different non-orthogonal channel access schemes in combination with wireless network coding in order to support a dense node deployment and flexible rate requirements. It can provide efficient in-band backhauling in the uplink for



Test Case #2 - Dense urban information society			
			fixed/moving relays.
		<i>Requirements</i>	Relay nodes in the network
		<i>Expected Gain</i>	Gain in spectral efficiency or better BLER (reliability) for the same transmitted power
	T3.3 TeC 5	<i>Solution</i>	IDMA as a non-orthogonal channel access scheme in combination with network coding allows for a very flexible design of MAC and BC phase in order to support a dense node deployment and flexible rate requirements.
		<i>Requirements</i>	Limited mobility
		<i>Expected Gain</i>	Spectral efficiency/user throughput: Expected gain 43% compared to non-optimized IDMA system
	T3.3 TeC 8	<i>Solution</i>	D2D relaying techniques to enhance link-level BER performance, which can potentially be translated into throughput increase.
		<i>Requirements</i>	UEs capability for D2D relaying.
		<i>Expected Gain</i>	Expected Gain of 1-6 dB in the BER vs transmitted power curve (rate increase)
Specific Challenge		Increase area spectral efficiency and served traffic volume density.	
	T3.1 TeC 1	<i>Solution</i>	Deployment of large aperture massive arrays along building facade or along the walls inside very large rooms (for large venues).
		<i>Requirements</i>	New infrastructure where large panels of antennas can be deployed.
		<i>Expected Gain</i>	Spectral efficiency and energy efficiency gains under evaluation.
	T3.1 TeC 8	<i>Solution</i>	Proposed architecture with a co-channel deployment of macro BSs equipped with large antenna arrays and small cells that explicitly targets a scenario with a high number of UEs.
		<i>Requirements</i>	Channel and interference covariance matrix need to be estimated at the BSs.
		<i>Expected Gain</i>	Area SE (Small Cells, UL): average gain of 100%. Area SE (Small Cells, DL): average gain of 50%. Area SE (macro, UL): average gain of 200%. Area SE (macro, DL): average gain of 150%.
	T3.1 TeC 11	<i>Solution</i>	A large rectangular array of active antennas is deployed where the spatial degrees of freedom are used to serve as many users as antennas available by SDMA.
		<i>Requirements</i>	Accurate channel estimate at the BS (in TDD systems) and MS mobility limitation.
		<i>Expected Gain</i>	Sum SE compared to LTE-A (8 antennas): x10 to x20 User SE compared to LTE-A (8 antennas): x10 to x20
Specific Challenge		Increase the spectral efficiency with low complexity.	
	T3.1 TeC 1b	<i>Solution</i>	Multiplexing of a large number of data streams with a DFT based spatial multiplexing approach that has low complexity.
		<i>Requirements</i>	Shapes and positioning of antennas (aligned linear arrays and aligned circular arrays). Slight misalignments can be corrected by the MRT scheme.
		<i>Expected Gain</i>	Complexity reduction, $x3 \cdot 10^{-5}$ improvement.



Test Case #2 - Dense urban information society			
			Spectral Efficiency, x166 improvement.
Specific Challenge		Increase spectral efficiency and reduce transmitter power.	
T3.1 TeC 7	<i>Solution</i>		3D BF by Massive MIMO using higher frequency bands allows to multiplex a large number of data streams with reduced transmitted power.
	<i>Requirements</i>		Accurate CSI.
	<i>Expected Gain</i>		Traffic value density and experienced user throughput: average SNR to achieve 20 Gbps throughput can be reduced by 17 dB at same transmitter power.
Specific Challenge		Increase user throughput in UL. Provide availability and reliability of 95 % Reduce energy consumption and cost of UEs	
T3.1 TeC 9	<i>Solution</i>		Use of a widely linear (WL) algorithm that improves the EVD-based channel estimation to alleviate pilot contamination and reduce the Mean Square Error (MSE) of channel estimates.
	<i>Requirements</i>		Works with i.i.d. fast-fading channel with prior knowledge of slow-fading coefficient at the BS.
	<i>Expected Gain</i>		User throughput: up to 60 Mbps, x2 compared with state of the art [NL12]. Error rate: x2 better compared with [NL12]. MSE of channel estimate reduced to less than 50% of [NL12].
Specific Challenge		Increase spectral efficiency with CoMP with imperfect CSI and feedback or backhaul latency.	
T3.2 TeC 1	<i>Solution</i>		CoMP transmission mode switching, robust resource allocation, backhaul load reduction
	<i>Requirements</i>		High reliable feedback and backhaul channels, low and moderate user mobility
	<i>Expected Gain</i>		Cell throughput Cell-edge throughput
T3.2 TeC 2b	<i>Solution</i>		Make better use of the delayed CSIT period
	<i>Requirements</i>		High enough SNR
	<i>Expected Gain</i>		User throughput Spectral efficiency
Specific Challenge		Increase spectral efficiency and relax feedback and backhauling requirements	
T3.2 TeC 2	<i>Solution</i>		Reduce the feedback needed for CoMP schemes without degradation of the total throughput, balancing the period of updating the CSI and the codebook size for the feedback.
	<i>Requirements</i>		Not too high speed of UEs
	<i>Expected Gain</i>		Feedback reduction min: 16% for 50km/h to max: 76% for 15km/h and the used codebook size.
T3.2 TeC 3	<i>Solution</i>		Interference mitigation with relaxed backhauling requirements by an offline agreement on the placement of the interference components.
	<i>Requirements</i>		Synchronization between BSs, efficient data sharing or caching, moderate mobility
	<i>Expected Gain</i>		Average cell-edge spectral efficiency. Expected gain: 0-300% (dependent on the system configuration).



Test Case #2 - Dense urban information society			
	T3.2 TeC 6	<i>Solution</i>	Combining the proposed IA scheme with scheduling and clustering allows the serving of a large number of users, while eliminating the need for feedback, and delivering high spectral efficiency.
		<i>Requirements</i>	TDD architecture, perfect backhaul links between micro BSs and macro BS, synchronization within each cluster of micro BSs and users
		<i>Expected Gain</i>	High spectral efficiency. Lower latency since low-rate feedback is no longer needed. Scheduling can improve the availability.
Specific Challenge		Enable the possibility to replace wired backhaul with wireless relaying	
	T3.3 TeC 1	<i>Solution</i>	Jointly solve the two-way (uplink + downlink) problem instead of treating it as sequence of one-way problems. Use the ideas of wireless network coding to jointly serve multiple communications flows.
		<i>Requirements</i>	Antipodal (non-interfering) users and relays, full CSI at the different nodes
		<i>Expected Gain</i>	Spectral efficiency: Expected gain 50–100%.
Specific Challenge		Increase spectral efficiency of edge users supported by relays	
	T3.3 TeC 3	<i>Solution</i>	Allow concurrent transmissions with interference cancellation to fully recover the multiplexing gain loss caused by the HD relaying. As a result, high spectral efficiency of edge users supported by relays can be provided.
		<i>Requirements</i>	Multiple relays with buffer, A good quality of CSI estimation and feedback for precise interference cancellation
		<i>Expected Gain</i>	Spectral efficiency: Expected gain 45–100% compared to the state-of-the-art HD relaying scheme, 30–400% compared to the conventional SFD-MMRS scheme without IRI consideration.
Reduce Energy Consumption			
Specific Challenge		Save energy without BLER degradations at high speeds (up to 300kmph).	
	T3.1 TeC 6	<i>Solution</i>	Predictor antennas are added on the roof of the vehicle and the complexity of the physical layer is increased so that channel prediction is never outdated, whatever the speed of the vehicle.
		<i>Requirements</i>	GPS is needed on the vehicle to provide speed measurement.
		<i>Expected Gain</i>	Transmitted Energy Saving, x1 to x30 improvement. BLER, x1 to x100 improvement.
Specific Challenge		Reduce energy consumption and cost of infrastructure and UEs. Increase availability and reliability.	
	T3.1 TeC 10	<i>Solution</i>	Transceiver complexity is reduced with minimal information exchange between transmitter nodes to realise the proposed algorithm based on random matrix theory for large antenna regime
		<i>Requirements</i>	Exchange path loss values of active users between



Test Case #2 - Dense urban information society			
			coordinating BSs in the network, i.e. improved x2 type interface is required.
		<i>Expected Gain</i>	Transmit power reduction. Reduced signalling between network nodes (backhaul traffic).
Specific Challenge		Reduce energy consumption in deployments with a large number of transmitting nodes with good overlapping in coverage areas	
	T3.2 TeC 15	<i>Solution</i>	Allow cooperation between transmitting nodes to dynamically switch off unnecessary nodes in low load condition and improve performance of the remaining nodes with Joint Transmission or Dynamic Point Selection/Blanking.
		<i>Requirements</i>	Centralized architecture with centralized scheduling, power saving features in transmitting nodes to enable sleep mode.
		<i>Expected Gain</i>	Overall BS power saving up to 27% in low to medium traffic condition with nowadays nodes power models.



Test Case #3 – Shopping Mall			
Increase Spectral Efficiency			
Specific Challenge		Increase spectral efficiency, capacity and coverage.	
	T3.3 TeC 4	<i>Solution</i>	Different non-orthogonal channel access schemes in combination with wireless network coding in order to support a dense node deployment and flexible rate requirements. It can provide efficient in-band backhauling in the uplink for fixed/moving relays.
		<i>Requirements</i>	Relay nodes in the network
		<i>Expected Gain</i>	Gain in spectral efficiency or better BLER (reliability) for the same transmitted power
Specific Challenge		Increased number of connections within the cell without increasing the spectrum resource used.	
	T3.3 TeC 7	<i>Solution</i>	Allow cooperation between cellular links and D2D links. Further improvement will be obtained by introducing underlay communication with the cooperating D2D link.
		<i>Requirements</i>	Proximity communications where several devices close to each other want to communicate. Discovery of D2D links within the cell.
		<i>Expected Gain</i>	Doubled number of connections per radio resource. Increased data rate of D2D link from 0 to 800% of that of the cooperating cellular user.
Specific Challenge		Deal with challenging co-channel interference in dense cell deployments	
	T3.2 TeC 12	<i>Solution</i>	Advanced UE receivers with IC/IS capabilities assisted by the network through signalling of interference signal transmission parameters and/or network side coordination among co-operative transmission nodes in order to enhance the interference estimation accuracy at UE receivers and improve the IC/IS performance.
		<i>Requirements</i>	Depending on the type of NA IC/IS receiver, different amount of interference signal information is required. Such assistance information may consist of different combinations of the following: information enabling a) interfering link channel estimation, b) enhanced symbol-level MIMO detection, c) decoding of interfering codeword.
		<i>Expected Gain</i>	User throughput through SINR gain (depending significantly on the interference profile studied): <ul style="list-style-type: none"> • from 0.5 dB up to 3 dB for E-LMMSE-IRC over that of the non-NA baseline receiver. • +1.5 dB gains for SLIC compared to E-LMMSE-IRC for specific high INR interference profiles. • even more sizeable gains in case of L-CWIC with low aggressor MCS#.



Test Case #4 – Stadium			
Increase Spectral Efficiency			
Specific Challenge		Increase spectral efficiency with high 3D beamforming gain enabled by accurate channel estimation	
T3.1 TeC 4	<i>Solution</i>	Blind estimation of channel covariance improved thanks to the estimation of the random fast-fading phase components of the strongest paths at UE, that are feed back to the serving base station.	
	<i>Requirements</i>	The UEs are required to make phase estimation by a subspace-based direction of arrival algorithm, and feed the estimated phases back to the serving base station.	
	<i>Expected Gain</i>	Gains to be evaluated	
Specific Challenge		Increase spectral efficiency, capacity and coverage.	
T3.3 TeC 4	<i>Solution</i>	Different non-orthogonal channel access schemes in combination with wireless network coding in order to support a dense node deployment and flexible rate requirements. It can provide efficient in-band backhauling in the uplink for fixed/moving relays.	
	<i>Requirements</i>	Relay nodes in the network	
	<i>Expected Gain</i>	Gain in spectral efficiency or better BLER (reliability) for the same transmitted power	
Reduce Energy Consumption			
Specific Challenge		Reduce energy consumption in deployments with a large number of transmitting nodes with good overlapping in coverage areas	
T3.2 TeC 15	<i>Solution</i>	Allow cooperation between transmitting nodes to dynamically switch off unnecessary nodes in low load condition and improve performance of the remaining nodes with Joint Transmission or Dynamic Point Selection/Blanking.	
	<i>Requirements</i>	Centralized architecture with centralized scheduling, power saving features in transmitting nodes to enable sleep mode.	
	<i>Expected Gain</i>	Energy saving up to 27% in low to medium traffic condition with nowadays nodes power models.	

Test Case #6 – Traffic Jam			
Increase Spectral Efficiency			
Specific Challenge		Increase spectral efficiency and relax feedback and backhauling requirements	
T3.2 TeC 2	<i>Solution</i>	Reduce the feedback needed at the CoMP scheme without degradation of the total throughput, balancing the period of updating the CSI and the codebook size for the feedback.	
	<i>Requirements</i>	Not too high speed of UEs	
	<i>Expected Gain</i>	Feedback reduction min: 16% for 50km/h to max: 76% for 15km/h and the used codebook size.	



Test Case #7 – Blind Spots			
Improve backhaul communication between the hotspots and the network			
Specific Challenge		Increase throughput and reduce latency	
T3.3 TeC 10	Solution	Increase throughput for the broadcast phase of two-way relaying by MU-MIMO like precoding techniques performed by the relay station and suppress interference by interference cancellation at the receiver's side. The delay is reduced by applying only two phases.	
	Requirements	Limited mobility of vehicular hotspots and UEs. Multiple antennas available at the RS.	
	Expected Gain	Latency, Expected Gain 33-50% Experienced user throughput, Expected Gain 50-100%	

Test Case #8 – Real-time remote computing for mobile terminals			
Reduce Energy Consumption			
Specific Challenge		Avoid to build new infrastructures	
T3.3 TeC 9	Solution	By using D2D communication and cooperating with each other, less energy is required to send the same amount of data of each active VUE in the cooperative transmission than the individual VUE-to-BS communications.	
	Requirements	D2D communication capability of VUEs	
	Expected Gain	Energy efficiency gains to be evaluated	

Test Case #9 – Open Air Festival			
Increase Spectral Efficiency			
Specific Challenge		Increase spectral efficiency with high 3D beamforming gain enabled by accurate channel estimation	
T3.1 TeC 2	Solution	Allocate near optimal transmit power to pilot and data symbols, minimizing the mean square error of the received data symbols and coordinating the pilot power allocation among the multiple cells.	
	Requirements	Backhaul network that allows multi-cell coordination. However, this coordination is on the 100 ms level, so the backhaul requirement is not too stringent.	
	Expected Gain	Improved data rates, 5 – 30 %, Energy efficiency, 5 – 30 %	
T3.1 TeC 4	Solution	Blind estimation of channel covariance improved thanks to the estimation of the random fast-fading phase components of the strongest paths at UE, that are fed back to the serving base station.	
	Requirements	The UEs are required to make phase estimation by a	



Test Case #9 – Open Air Festival			
			subspace-based direction of arrival algorithm, and feed the estimated phases back to the serving base station.
		<i>Expected Gain</i>	Gains to be evaluated
Specific Challenge		Increase spectral efficiency, capacity and coverage.	
	T3.3 TeC 4	<i>Solution</i>	Different non-orthogonal channel access schemes in combination with wireless network coding in order to support a dense node deployment and flexible rate requirements. It can provide efficient in-band backhauling in the uplink for fixed/moving relays.
		<i>Requirements</i>	Relay nodes in the network
		<i>Expected Gain</i>	Gain in spectral efficiency or better BLER (reliability) for the same transmitted power
Extend Coverage			
Specific Challenge		Support large number of users compacted in a small area with limited infrastructure cost	
	T3.2 TeC11	<i>Solution</i>	D2D communication with decentralized interference aware scheduler
		<i>Requirements</i>	D2D support, beacon messages to signal interference status
		<i>Expected Gain</i>	Coverage: possibility to reach highly interfered users far away from the transmitter (which are not reachable with legacy solution). See Appendix C section 9.2.11. Mean throughput: Expected Gain +5% (so no loss due to the distributed D2D approach)
	T3.3 TeC 6	<i>Solution</i>	D2D communication uses the same spectrum. Proposed solution provides higher data rates with MIMO and PLNC. Coverage extends due to relay assisted D2D. Spectrum is utilized properly.
		<i>Requirements</i>	CSI, Relay nodes. Cooperation between BS-MS and D2D to enhance the accuracy of optimum precoding and decoding
		<i>Expected Gain</i>	Coverage extension to be evaluated

Test Case #12 – Traffic safety and efficiency			
Support real time communication			
Specific Challenge		Support high relative velocity (up to 500 km/h) and provide very low end to end latency (<5ms)	
	T3.2 TeC 16	<i>Solution</i>	Use of non-coherent communication that enables the communication without any channel state information at the receiver (CSIR), avoiding the effect of imperfect CSIR on the system performance. This TeC could potentially reduce the Frame Error Rate (FER) in high mobility scenarios.
		<i>Requirements</i>	New signal processing capabilities at the TPs and UEs to work with Grassmannian signaling.
		<i>Expected Gain</i>	Expected gains in terms of relative velocity under evaluation. The gain will be attained by improving the FER achieved with mobility



8 Appendix B: Simulation Baselines

8.1 Simulation Baseline for Task 3.1

This section discusses the common baseline assumptions for the two research clusters in task 3.1. These assumptions are necessary to compare results from different partners. These assumptions are not mandatory but strongly recommended for benchmarks and the generation of final results at the end of the project. In the following, we distinguish between assumptions for link and system level studies.

Link level studies are considering only a single macro BS and the common simulation baseline should be the usage of a three dimensional channel model. At the current project status the channel model which will be provided by WP1 is not finished yet but it is assumed to be an extension from WINNER+ type of modelling, in the best case with spatial consistency included. The requirements on the channel model for link-level studies which are specific for task 3.1 are summarized in the following table. For other assumptions such as modulation, channel coding or MIMO configurations, the common baseline parameters follow the link-level alignment of Section 3 in D6.1 [METIS61].

Table 8.1: T3.1 RC1 and RC2 alignment for link level studies

Channel Model	
Channel model type	METIS 3D channel model (assumed to be extended from WINNER+ type modelling principle)
3 dimensional	yes
Spatial correlation	yes
Link level assumptions	Section 3, in D6.1 [METIS61]

System level studies require some more parameter assumptions on top of the 3D channel model. The most important one are an outdoor macro BS with a minimum number of 80 active antennas in the array, a backhaul connection via fiber, outdoor mobile stations with stationary or small movement and if considered 4 or more small cells equipped with 2 or more antennas in a not optimized deployment. All the parameters are summarized in the following table. Note, that these assumptions are only the lowest common denominator between all partners and there are no limitations or requirements on additional parameters.

Table 8.2: T3.1 RC1 and RC2 common baseline for system-level assumptions

Large antenna array at macro BS	
Number of antennas	Equal or greater than 80, each an active antenna with a RF chain for beamforming
Number of nodes	1 for link level >1 for multi-cell
Small cells (outdoor, optional)	
Number of antennas	Equal or greater than 2
Number of nodes	Equal of greater than 4
Backhaul	Connected by fiber
Synchronization with macro BS	perfect



Deployment	Not optimized (random)
Mobile Stations	
Number of nodes	Full buffer: Equal or greater than 60 Finite buffer: According to MS arrival process
Mobility	Stationary or slow moving (3 km/h)
Deployment	Outdoor Random for macro BS Hot spots for small cells
Traffic model	RC1: Full buffer, finite buffer RC2: Full buffer
Channel Model	
Type	METIS 3D channel model (assumed to be extended from WINNER+ type modelling principle)
3 dimensional	yes
Spatial correlation	yes

8.2 Simulation Baseline for Task 3.2

The Dense Urban Information Society (TC2) ([METIS61], Sect. 4.2) has been recognized as the most targeted TC by the technology components developed in T3.2 ([METIS31], Sect. 3.4). Hence, in this section we develop a common simulation setup for TC2 to compare and evaluate the different TeCs.

In [METIS61] section 3.3.3 “calibration case 3” has already been defined as a possible simplified model for TC2, where 4 macro sectors and 4 micro base stations are deployed in a grid of 2 x 2 buildings. However, as T3.2 deals with coordinated multi-point schemes, in order to properly evaluate the coordination among the BSs, we need to deviate from calibration case 3 by increasing the number of BSs. Therefore, we consider the network deployment of Figure 8.1, with a grid of 3 x 3 buildings, 3 macro sectors (red squares in the figure) and 9 micro BSs (blue circles in the figure), each composed of two sectors transmitting in opposite directions. Similar to calibration case 3, we assume that each building has a square shape of 120 m x 120 m, has 6 floors (each of 3.5 m height), and both sidewalks and lanes surrounding the buildings are 3 m wide. Each macro sector is located on the edge of the central building 5 m above the top, whereas each micro BS is 10 m above the ground and 3 m away from the middle point of the edge of the closest building. Then, we assume 210 outdoor static user equipments (10 UEs per sector on average) and a full buffer traffic model.

Regarding the large scale fading, we consider i) a 3D antenna radiation pattern ([METIS61], p. 14) and ii) the propagation scenarios (PSs) described in [METIS61] section 8.1. In detail, the path-loss between a macro sector and a UE is computed by using PS3, which assumes that part of the signal reaches the UE via diffraction, while the path-loss between a micro sector and a UE is computed by using PS1, which distinguishes the main street (where the micro BS is located) from perpendicular and parallel streets.

For the small scale fading, we consider as a first approach the ITU-R M.2135 models summarized in [METIS61], Table 8.2.

Note that the MATLAB code to reproduce the described network deployment is available on the METIS website [MC13a], [MC13b].

Some additional and different features have been agreed specifically for each research cluster. In detail, RC1, which focuses on improvements to classical coordination techniques, removes some ideal assumptions by considering a backhaul latency between 5 ms and 50 ms, and a CSI feedback delay of 5 ms. On the other hand, TeCs developed in RC2, which focuses on interference alignment, are still exploratory researches and consider a different system model.

Finally, we emphasize that this simulation setup has been defined to compare some of the TeCs in a similar scenario, but it does not represent the only focus of T3.2. By consisting of 17 TeCs, T3.2 is quite broad and, as 12 TCs are targeted in METIS ([METIS11] Sect. 3.3), not all the TeCs will be evaluated in the considered setup. In fact, some TeCs are focused on different TCs ([METIS31] Sect. 3.4), for instance TeC15 which targets the Stadium (TC4), whereas other TeCs are theoretical analyses, for instance TeC2b, where simulations of a very specific TC are out of the scope.

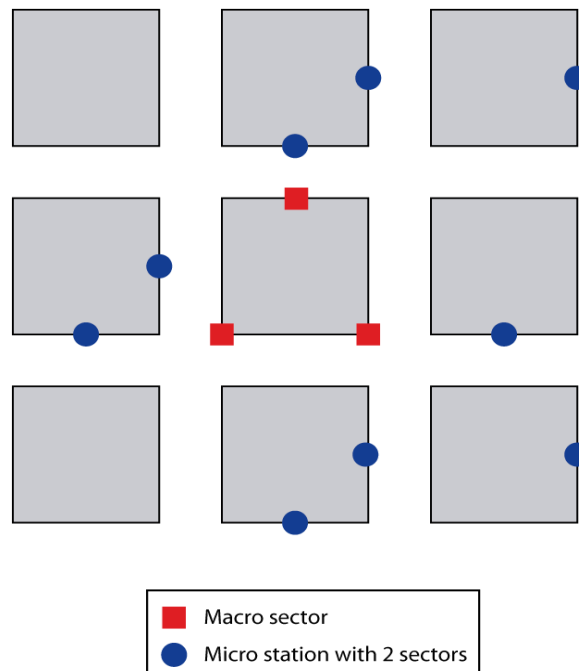


Figure 8.1 BS deployment considered for TC2 in T3.2

8.3 Simulation Baseline for Task 3.3

This section discusses the simulation baseline assumptions for the two research clusters in task 3.3. As described in the next sections the research cluster 1 partners are mostly concentrating on test case 2 dense urban information society. On the other hand each partner of the research cluster 2 is considering solutions for different test cases. Results provided in this report are obtained with different simulation assumptions. In order to compare results from different partners, it was proposed to define common simulation assumptions, that not necessary are the best one for each particular technology component but allow to investigate them in a common framework.

The deployment and simulation assumptions are quite similar to task 3.2. In Figure 8.2 the deployment considered in task 3.3 is visualized considering antenna patterns. This is the same deployment as in task 3.2.

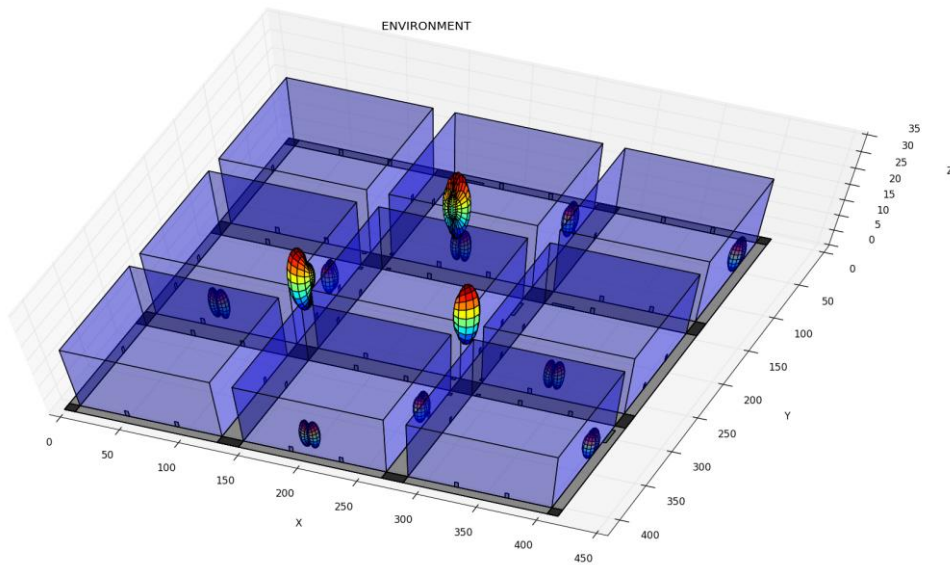


Figure 8.2 Deployment considered for TC2 in T3.3

One of the important research topics in task 3.3 focuses on a network densification exploiting spectrally efficient relaying and wireless in-band backhauling in TDD systems. To properly evaluate this in simulations, all stations should operate using the same carrier frequency. This is different compared to simulation guidelines for TC2 provided in [METIS61]. In Table 8.3 exemplary simulation assumptions are shown. These assumptions are based on [METIS61] section 3.3.3 “calibration case 3”, but consider the same carrier frequency for macro and micro stations. In Figure 8.3, wideband SINR map for downlink transmission is presented as a reference, when Table 8.3 parameters are used. These assumptions are not mandatory but recommended for generation of comparable simulation results.

Table 8.3: T3.3 Exemplary simulation assumptions

Channel Model	Macro	Micro
TX power [dBm]	42	37
Cell range expansion [dB]	0	5
Carrier frequency [MHz]	2600	2600
Bandwidth [MHz]	20	80
Antenna gain [dB]	17	17
Tilt [degrees]	12	0

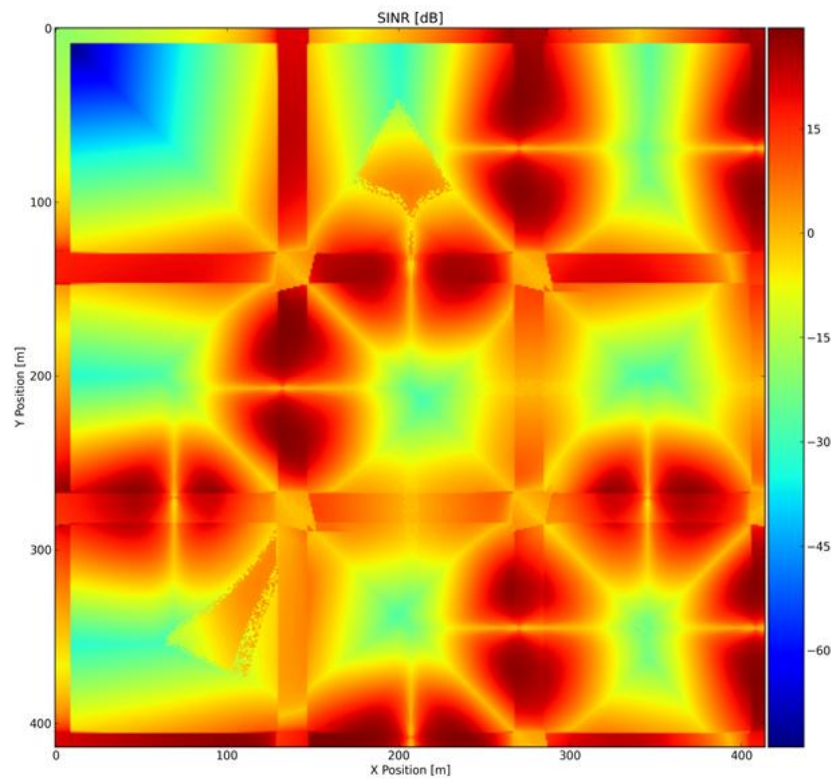


Figure 8.3 Wideband SINR distribution.

9 Appendix C: Preliminary Simulation Results

This appendix reports more detailed information on simulation results obtained in the first part of the METIS project for the different technology components described in the previous sections.

9.1 Preliminary Results for Task 3.1

9.1.1 T3.1 TeC.01 MIMO communications with large aperture massive array systems

Preliminary results about the deployment of large aperture arrays comprised of a massive number of antennas are here presented. Such arrays can be deployed in new infrastructures, such as airport halls, shopping malls, stadium, concert stages, etc to serve as access points for wireless communications to multiple users.

One set of results is reported about MIMO point-to-point channel characteristics in line of sight (LOS). The main message is that the MIMO channel can be very well conditioned (or equivalently the inter-links are close to orthogonal) provided that some conditions on array aperture at both sides and inter-user distance are fulfilled. The metric that is shown is the condition number. The user has 2 antennas (there are 2 eigenvalues) and moves along the broadside of the large array. We study two different effects:

- Stretching of the array:** in Figure 9.1 we show the effect of the array aperture on the channel condition number. For a fixed number of antennas of 101, we stretch the massive array from an aperture of 1.5 meters, where the inter-element spacing d_A is equal to half the wavelength, to an aperture of 21 meters, where the inter-element spacing is equal to 14λ . We observe that the condition number is equal to 0dB at regular intervals along the broadside direction. The deviation of the condition number w.r.t. to 0dB gets reduced as the aperture increases.
- Densification of the array:** in Figure 9.2 we show the effect of the number of antennas on the channel condition number. For a fixed aperture of 3 meters, we increase the number of antennas of the massive array from 4 antennas to 50 antennas. We observe that the deviation of the condition number w.r.t. to 0dB gets reduced as the number of antennas increases. Furthermore, increasing the number of antennas from 10 to 50 antennas does not change much the range of the condition number at a distance larger than 5 meters.

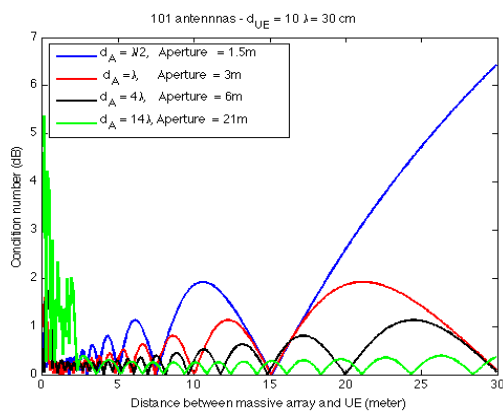


Figure 9.1: Stretching of the array. Condition number vs. the distance between the massive array and the UE, for a fixed number of antennas of 101 and an increasing aperture.

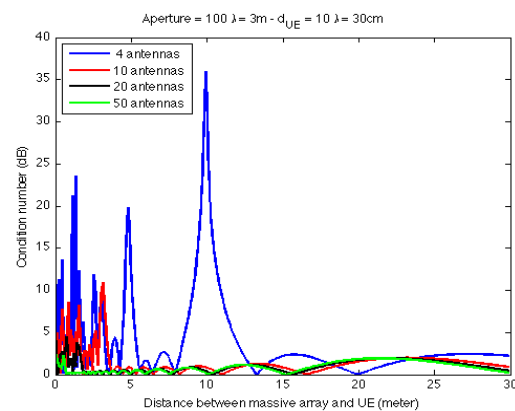


Figure 9.2: Densification of the array. Condition number vs. the distance between the massive array and the UE, for a fixed aperture of 3 meters and an increasing number of antennas.

9.1.2 T3.1 TeC.01b DFT based spatial multiplexing and maximum ratio transmission for mm-wave large MIMO

The spectral efficiencies achieved by Discrete Fourier Transform based spatial multiplexing and maximum ratio transmission (DFT-SM-MRT) are assessed for particular values of the following parameter derived from the diffraction theory in optics: $m = \frac{R^2}{\lambda D}$, where R is the radius of the circular array (R being also half of the length of the linear array), D is the transmitter-receiver distance and f is the carrier frequency (and the corresponding wavelength). These values are chosen so that they correspond to mm-waves short range communications.

Table 9.1 summarizes the results for a chosen $m = 40$. Here are two examples of scenarios with $m = 40$: $R = 3$ m, $D = 45$ m and $f = 60$ GHz, or $R = 3$ m, $D = 75$ m and $f = 100$ GHz.

The three following effects are assessed separately and also combined, to assess the robustness of DFT-SM-MRT with respect to misalignment and NLOS: a slight translation of the arrays, a slight rotation of the arrays, one reflection over a roof.

Depending on the scenario, DFT-SM-MRT achieves hundreds of bits/s/Hz. In comparison with SVD, DFT-SM-MRT achieves 1/3 to 1/14 of SVD performance, with a complexity which is around 3×10^{-5} times lower, for the considered number of antennas ($N = 512$).

Table 9.1: DFT-SM-MRT performance at $m = 40$

Effects	DFT-SM-MRT spectral efficiency (bits/s/Hz)		Ratio between DFT-SM-MRT and SVD spectral efficiencies	
	Circular Array	Linear Array	Circular Array	Linear Array
Translation	770	224	>1/3	~3/4
Rotation	1000	215	~1/3	~5/7
Reflection	440	135	>1/7	~4/9
All	215	189	>1/14	~5/8

Compared to a mm-wave SISO system (achieving 6bits/s/Hz with 64QAM), the gain of the proposed system, in terms of spectral efficiency, reaches around $1000/6$, i.e. 166.

To conclude this section, DFT-SM-MRT provides high spectral efficiency without inter-antenna spacing optimization with respect to the distance, and is robust to misalignment plus one reflector.

This results have been fully described in the conference paper [PTRC+14].

9.1.2.1 Acronyms

DFT	Discrete Fourier Transform
MRT	Maximum Ratio transmission
NLOS	Non Line of Sight
SM	Spatial Multiplexing
SVD	Singular Value Decomposition

9.1.2.2 References

[RSM+13] T.S. Rappaport, Shu Sun; R. Mayzus, Hang Zhao, Y. Azar, K. Wang, G.N. Wong, J.K. Schulz, M. Samimi, F. Gutierrez, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," Access, IEEE vol.1, no., pp.335-349, 2013.



[YYH+10] D. Yang, L.-L. Yang, L. Hanzo, "DFT-Based Beamforming Weight-Vector Codebook Design for Spatially Correlated Channels in the Unitary Precoding Aided Multiuser Downlink," in Proc. IEEE Int. Conf. Comm. 2010, vol., no., pp.1,5, 23-27 May 2010.

[EJ+12] O. Edfors, A.J. Johansson, "Is Orbital Angular Momentum (OAM) Based Radio Communication an Unexploited Area?," IEEE Trans. on Antennas and Propagation , vol.60, no.2, pp.1126-1131, Feb. 2012.

[PTRC+14] D.-T. Phan-Huy, A. Tölli, N. Rajatheva, E. De Carvalho, "DFT based spatial multiplexing and maximum ratio transmission for mm-wave large MIMO," IEEE WCNC 2014, Istanbul, Turkey, 6-9 Apr. 2014.

9.1.3 T3.1 TeC.02 Coordinated resource and power allocation for pilot and data signals in multicell SIMO systems

Figure 9.3 reports the mean square error (MSE) performance of the received uplink equalized data symbol using minimum mean square error (MMSE) receiver at the base station as a function of the uplink pilot power. We can see that proper pilot power allocation is important to minimize the MSE. For each antenna configuration, there are 2 curves that correspond to 50 dB and 60 dB path loss. The left hand side figure shows the MSE performance for correlated antennas, while the right hand side figure is with uncorrelated antennas. In both case, configuring the pilot power helps minimize the MSE. (See also [GGF+14].)

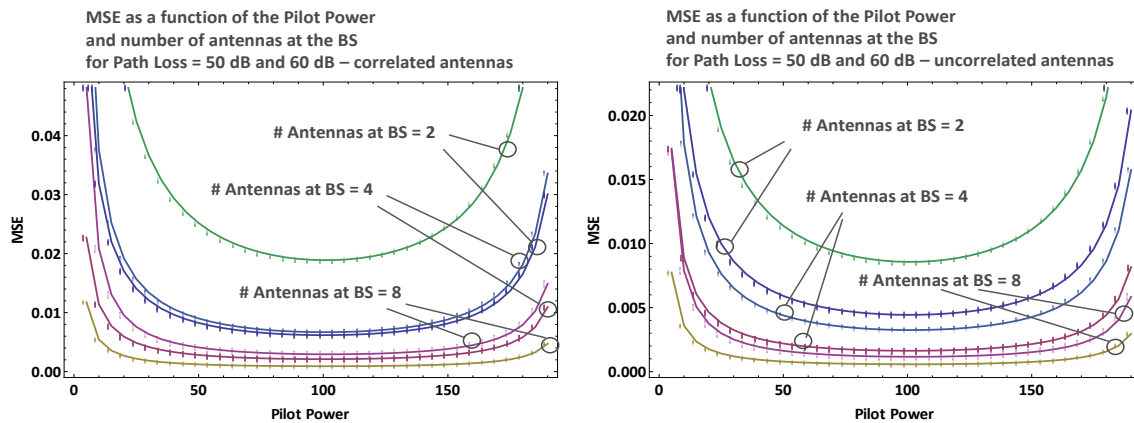


Figure 9.3: Mean square error (MSE) performance of the received uplink equalized data symbol

While the classical Distributed Iterative Channel Inversion (DICI) algorithm of [CAH+07] focuses on the coordinated **data power** assignment, it does not consider channel estimation errors. On the other hand, the coordinated approach to pilot assignment proposed by [YGF+13] does not tune the pilot power levels and does not take into account the problem of Pilot-to-Data-Power-Ratio (PTDPR) balancing. For practical systems, channel estimation errors and a constrained pilot-plus-data-power budget must be considered. The issue of PTDPR balancing is illustrated by the above figure that shows the mean square error (MSE) of the uplink received data symbols when the pilot power is tuned within the pilot-plus-data-power budget.

For the multi-cell system, a sum power minimization task that addresses the issue of minimizing the pilot-plus-data-power budget subject to a predefined SINR target per user can therefore be formulated as follows:

$$\begin{cases} \text{minimize } \sum_{k \in U} (P_k + P_k^p) \\ \text{s.t. } \gamma_k \geq \Gamma_k, \quad k \in U; \\ P_k + P_k^p \leq P_k^{\text{tot}} \end{cases}$$

In the problem formulation above, a set of fixed SINR targets (Γ_k) for each user k in the multi-cell system and a fixed total (uplink) power budget (P_k^{tot}) per user are assumed. A natural extension of this problem formulation, applicable for data traffic is to maximize the sum data rate such that a minimum SINR target is required for all users. Leveraging on the coordinated pilot power based channel estimation; we propose the modified DICI algorithm to compute both the pilot (P_k^p) and data (P_k) transmit power of user k to meet a predefined SINR target. Thus, the extended DICI algorithm can be used in realistic multi-cell systems in which users have a finite total power budget and in which both the pilots and data are affected by inter-cell



interference. A multi-cell system that explicitly considers and manages inter-cell interference for both pilot and data signals is presented and analysed in [GGF+14].

9.1.3.1 Acronyms

BS	Base Station
DICI	Distributed Iterative Channel Inversion
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
PTDPR	Pilot-to-Data-Power-Ratio
SINR	Signal-to-Interference-Plus-Noise-Ratio
UE	User Equipment

9.1.3.2 References

[CAH+07] R. Chen, J. G. Andrews, R. W. Heath, and A. Ghosh, "Uplink Power Control in Multi-cell Spatial Multiplexing Wireless Systems," *IEEE Trans. on Wireless Communications*, vol. 6, no. 7, pp. 2700–2711, July 2007.

[YGF+13] H. Yin, D. Gesbert, M. Filippou, and Y. Liu, "A Coordinated Approach to Channel Estimation in Large-Scale Multiple-Antenna Systems," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 2, pp. 264–273, February 2013.

[GGF+14] K. Guo, Y. Guo, G. Fodor and G. H. Ascheid, "Uplink Power Control with MMSE Receiver in Multi-Cell MU-Massive-MIMO Systems", submitted to *IEEE International Conference on Communications (ICC '14)*, Sydney, Australia, June 2014.

9.1.4 T3.1 TeC.04 Multi-cell MU-MIMO in real world scenarios – performance evaluation of EVD-based channel covariance feedback and multi-path extraction in massive MIMO systems

Figure 9.4 shows the downlink user throughput distributions with covariance feedback and ideal path extraction-based channel estimation, where the extracted paths are selected based on large-scale gain metrics. We can see that the cumulative performance of the 6 strongest paths reaches the performance of uplink covariance feedback with transformation. In case of downlink covariance feedback, at least 10 paths should be estimated.

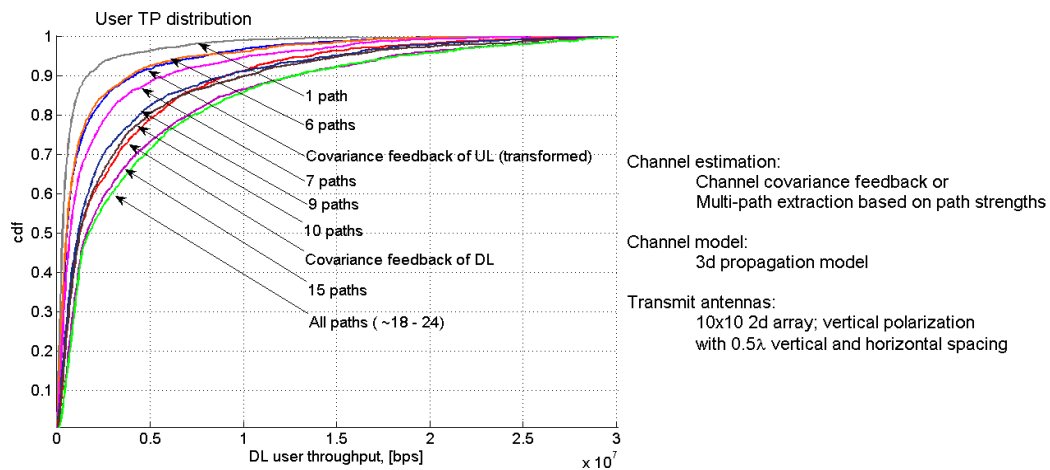


Figure 9.4: Downlink user throughput distributions with covariance feedback and ideal path extraction-based channel estimation

Eigen Value Decomposition (EVD) based channel covariance estimation methods that exploit the favourable propagation of the massive MIMO systems have been recently considered in TDD systems [NL12]. On the other hand, there have been studies that transform uplink channel covariance to downlink for FDD systems. However, the performance is limited under either duplex mode because of unknown fast fading coefficients. The overhead due to the estimation and feedback of the path phases is insensitive to the size of the base station antenna array; hence the multi-path phase estimation-based feedback can be feasible in massive MIMO systems, in contrast to conventional codebook-based feedback.

In the downlink, the received signal at UE under WSSUS model is given by [FN98]

$$x(t) = K \sum_{i=1}^L \alpha_i e^{2\pi f_D t + j\psi_i(\lambda)} a(\phi_i, \theta_i) s(t - \tau_i)$$

where K is the combined path loss and shadowing, L is the total number of paths, α is the fast fading coefficient, f_D is the Doppler frequency, λ is the carrier frequency, a is the deterministic antenna array response, and s is the transmitted signal. In FDD systems, only the DOAs remain unchanged between uplink and downlink according to reciprocal law.

The downlink fast fading effects of the strong paths can be estimated, and fed back to BS. A diagram of multi-path phase feedback between BS-UE is shown in Figure 9.5 below.

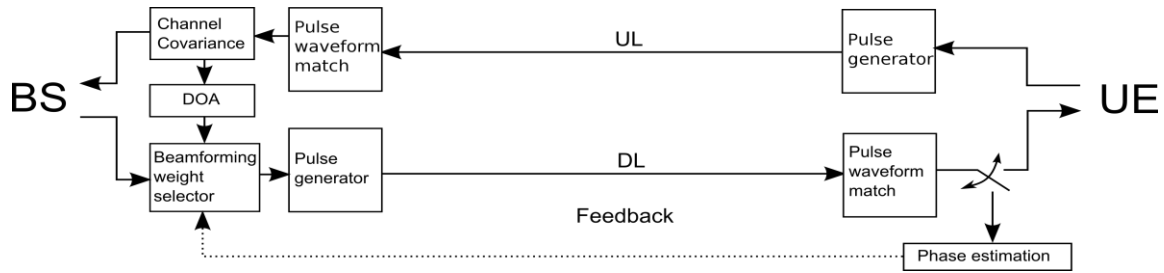


Figure 9.5: Diagram of multi-path phase feedback between BS-UE

9.1.4.1 Acronyms

BS	Base Station
CSIT	Transmit Channel State Information
DL	Downlink
DOA	Direction of Arrival
EVD	Eigen Value Decomposition
MIMO	Multiple Input Multiple Output
MU	Multi-user
TP	Throughput
UE	User Equipment
UL	Uplink
WSSUS	Wide Sense Stationary Uncorrelated Scattering

9.1.4.2 References

- [NL12] H. Q. Ngo, and E. G. Larsson, "EVD-based Channel Estimations for Multicell Multiuser MIMO Systems with Very Large Antenna Arrays," IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP '12), pp. 3249–3252, March 2012.
- [FN98] C. Farsakh and J. A. Nossek, "Spatial Covariance Based Downlink Beamforming in an SDMA Mobile Radio System," IEEE Transactions on Communications, vol. 46, no. 11, pp. 1497-1506, November 1998.

9.1.5 T3.1 TeC.05 Model Based Channel Prediction (MBCP)

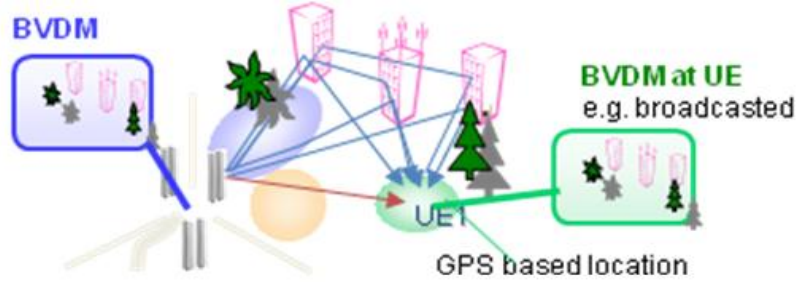


Figure 9.6: basic concept of model based channel prediction

In case of model based channel prediction [ZH13], eNB and UEs share the same model of the eNB surrounding. UEs report instead of the direct CSI its location information with respect to the model. In case of an ideal model, the eNB will be able to fully reconstruct the CSI by a sort of a ray-tracing simulation. The interesting aspect is that ideally a strong, but lossless feedback compression can be achieved, as at least for an ideal model the full wideband CSI for several radio channel components can be reconstructed from a single location information.

Applying known results from beamspace processing [SLH13] for a radio channel consisting of two multipath components the best case achievable accuracy for the main multi path parameters has been extended to a more realistic scenario with several hundreds of estimated multi path components. The potential channel prediction quality (NMSE: normalized mean square error) over distance one could expect for an estimation accuracy of the angle of arrival (AoA) of 2, 3 or 5° is depicted in the Figure 9.7 below.

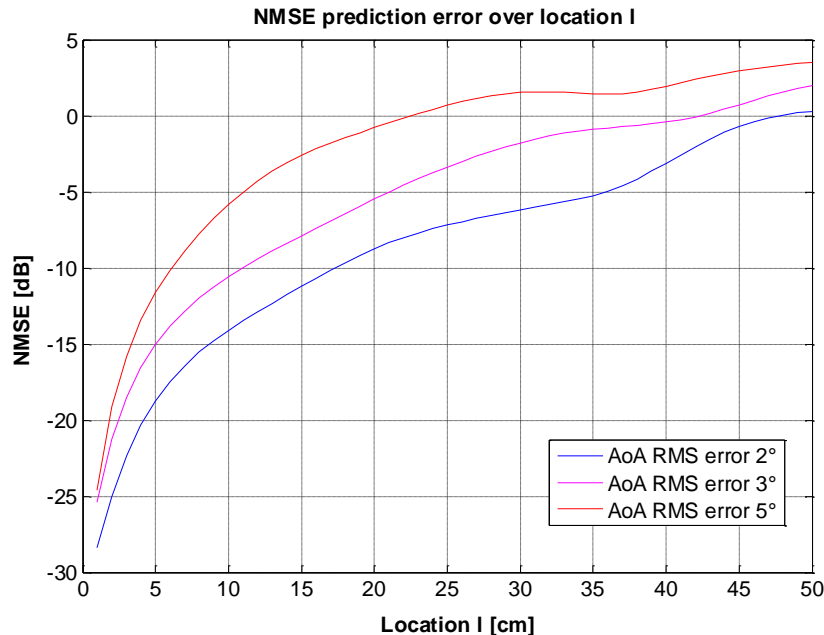


Figure 9.7: NMSE [dB] over prediction distance in cm. The wavelength λ is here 12cm, i.e. the blue line achieves an NMSE of about -18dB for 0.5λ . Parameter is the RMS error of the AoA estimate per MPC with $r/m/b$ equal to 2°/3°/5°.

According to Figure 9.8 there is a significant difference in the evolution of the prediction error for different PRBs or frequency bins. While for some PRBs the prediction is almost perfect even for 0.5 to 2 λ , for other PRBs the prediction fails already after few cm more or less completely.

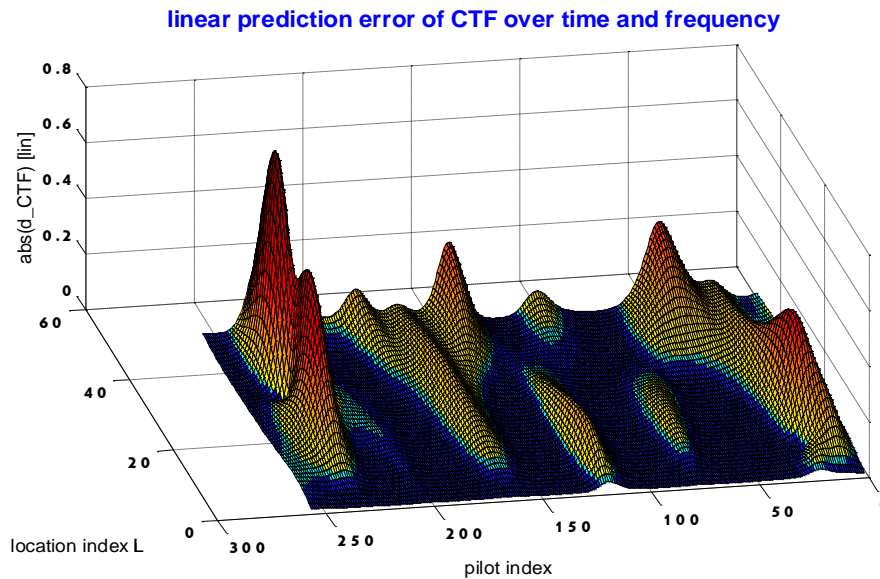


Figure 9.8: Typical evolution of the estimation error over time and frequency

Based on these results a novel low latency low rate feedback channel has been added reporting failed PRBs, i.e. PRBs for which the prediction error is above a certain threshold. That way for example the joint transmission precoder can be suitably adapted minimizing the corresponding performance losses. Simulations revealed significantly higher throughput for all UEs as long as the number of failed channel components remains sufficiently small.

9.1.5.1 Acronyms

AoA	Angle of Arrival
BVDM	Building Vector Data Map
MBCP	Model Based Channel Prediction
MPC	Multi Path Components
NMSE	Normalized Mean Square Error
PRB	Physical Resource Block
RMS	Root mean square

9.1.5.2 References

- [GHZ+12] N. Gresset, H. Halbauer, W. Zirwas, H. Khanfir, "Interference Avoidance Techniques for Improving Ubiquitous User Experience," IEEE VTM magazine, Dec 2012
- [MGH08] M. Milojević, G. Del Galdo, and M. Haardt, "Tensor-based framework for the prediction of frequency-selective time-variant MIMO channels", 2008 International ITG Workshop on Smart Antennas (WSA), 2008
- [PW12] N. Palleit, T. Weber, "Channel Prediction in Multiple Antenna Systems," International ITG Workshop on Smart Antennas (WSA'12), S. 1-7, Dresden, Germany, 2012
- [SLH13] J. Steinwandt, R. C. De Lamare, M. Haardt, "Beamspace direction finding based on the conjugate gradient and the auxiliary vector filtering algorithms," Journal on Signal Processing, Volume 93 Issue 4, pp. 641-651, April 2013
- [ZH13] W. Zirwas, M. Haardt, "Channel Prediction for B4G Radio Systems," VTCspring 2013, Germany, Dresden, June 2013

9.1.6 T3.1 TeC.06 Adaptive large MISO downlink with predictor antenna array for very fast moving vehicles

Very recently, for the particular purpose of large MISO Downlink (DL) Beamforming (BF) in TDD [YM13], a new scheme called Separate Receive and Training Antennas (SRTA) [PHH13], has been proposed to achieve high energy efficient wireless backhaul for fast moving vehicular relays. The vehicle roof is equipped with one Predictor Antenna (PA) at the front and several “Candidate Antennas” (CAs) aligned behind. The PA sends pilots in the UL and the BS computes BF weights. Among the CAs, a “Receive Antenna” (RA), responsible for data demodulation, is dynamically selected among the CAs as a function of the vehicle speed. The TDD frame is also dynamically extended as a function of the vehicle speed. The RA and the extended frame are computed to ensure that, during the DL phase, the RA is exactly at the position that was previously occupied by the PA during the UL phase.

As a reference for the study, we consider a conventional DL MISO BF TDD system, called Reference System (RS) with a fixed frame duration $t_0 = 2\text{ms}$, with 64 transmit antennas, Maximum Ratio Transmission (MRT) BF, an outer loop power control to meet a target SNR. 64QAM with coding rate $\frac{3}{4}$ and a target BLER of 1% is considered. We also consider SRTA with an adaptive frame duration $t_a(v)$ (where v is the speed) higher than t_0 , 3 CAs and one PA. The carrier frequency is 2GHz and the vehicle speed lies between 0 and 300kmph. A spatially correlated fading channel is modelled, in both Line of Sight (LOS) and Non LOS (NLOS) conditions. The energy saving is defined as the ratio of the energy required to achieve the target SNR with a single antenna at the Base Station over the energy required with all 64 antennas. Figure 9.9 below illustrates the RS and SRTA schemes.

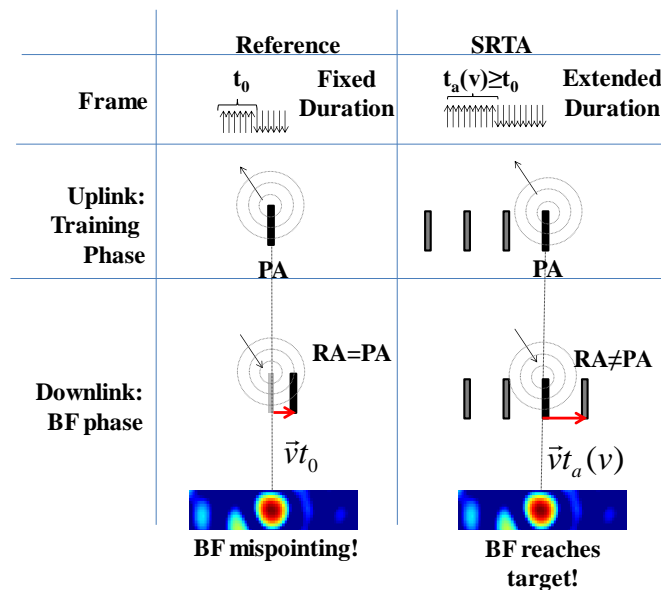


Figure 9.9: Separate receive and training antenna and reference schemes

First, we propose to enhance SRTA scheme by switching off some antennas to widen the beam when residual BF mispointing is too severe (i.e. when the achieved BLER is larger than 20%). Two schemes are proposed: the SRTA-Random Switch Off Scheme (SRTA-RSOS) and the SRTA-Border Switch Off Scheme (SRTA-BSOS). BSOS and RSOS are used on top of SRTA, to compensate for residual BF mispointing. In the case of BSOS, the antennas at the border of the linear arrays are switched off. In the case of RSOS, the antennas being switched off are randomly selected.

As a further improvement we propose, specifically for large MISO downlink beamforming in TDD, a new scheme called “Polynomial Interpolation” (PI). The objective is to provide a highly efficient wireless backhaul, in terms of energy consumption, for fast moving vehicular relays. The BS interpolates the measurements to predict the channel between the BS and the receive antenna, accurately.

Figure 9.10 illustrates the achieved BLER as a function of the vehicle speed. With RS, the performance degrades strongly for speeds larger than 50 kmph, reaching a BLER of 1. SRTA alone does not compensate all speeds. SRTA-BSOS and SRTA-RSOS improve the BLER, for most speeds. Figure 9.11 illustrates the energy saving e_s (which is the ratio of the power required with a SISO system over the power required with a large MISO system and adaptive beamforming) as a function of the vehicle speed. RS and SRTA use all antennas at the Base Station to focus the energy onto the vehicle and therefore achieve the maximum energy saving (which is around 20dB). SRTA-BSOS/RSOS mute some antennas to compensate mispointing, and therefore save less energy. The proposed SRTA-PI achieves the target BLER of 0.01 and reaches the maximum energy saving (20dB) at the same time. Compared to RS/SRTA/SRTA-BSOS/SRTA-RSOS, the BLER is improved by a factor of x100, and the energy saving by a factor of x30.

These results have been presented in the paper [PHSS+13].

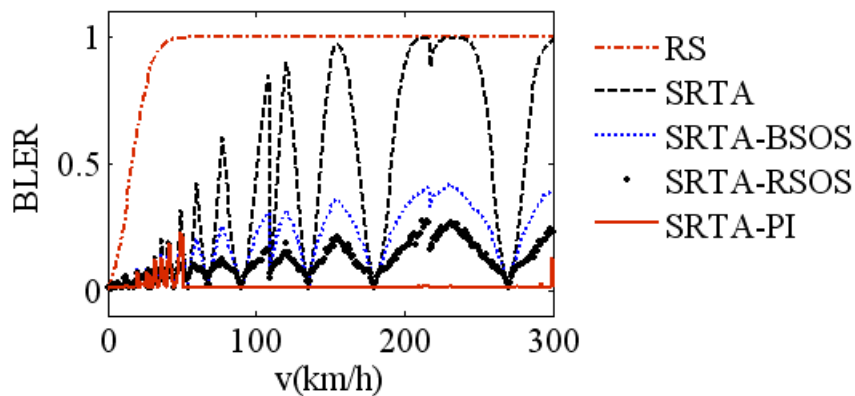


Figure 9.10: BLER versus speed

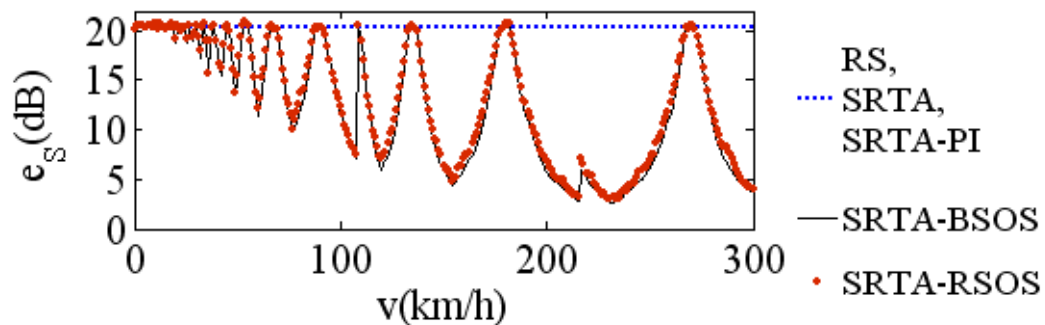


Figure 9.11: Energy Saving versus speed

9.1.6.1 Acronyms

BF	Beamforming
BLER	Block Error Rate
BSOS	Border Switch Off Scheme
CA	Candidate Antenna
DL	Downlink
LOS	Line of Sight
MISO	Multiple Input Single Output
MRT	Maximum Ratio Transmission
NLOS	Non Line of Sight



PA	Predictor Antenna
PI	Polynomial Interpolation
RA	Receive Antenna
RS	Reference System
RSOS	Random Switch Off Scheme
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SRTA	Separate Receive and Training Antennas

9.1.6.2 References

[YM13] Hong Yang, T.L. Marzetta, "Performance of Conjugate and Zero-Forcing Beamforming in Large-Scale Antenna Systems," Selected Areas in Communications, IEEE Journal on , vol.31, no.2, pp.172-179, February 2013

[PHH13] D.T. Phan Huy, M. H elard, "Large MISO Beamforming For High Speed Vehicles Using Separate Receive & Training Antennas," IEEE International Symposium on Wireless Vehicular Communications (WiVEC), Dreden, Germany, 2-3 June 2013.

[PHSS+13] D.-T. Phan-Huy, M. Sternad, T. Svensson, "Adaptive Large MISO Downlink with Predictor Antenna Array for very fast moving vehicles," 2013 International Conference on Connected Vehicles & Expo, Las Vegas, USA, 2-6 December 2013.

9.1.7 T3.1 TeC.07 Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments

In order to tackle the rapidly increasing data traffic, usage of higher frequency bands that can easily expand signal bandwidth has being widely studied for future wireless communication systems. DOCOMO has successfully achieved 10 Gbps packet transmission employing 11 GHz band 8x16 MIMO by field experiments in partnership with Tokyo Institute of Technology in December 2012 [NDP13], [SSO+13]. In addition, mobile services using the higher frequency bands can be flexibly introduced by Phantom Cell architecture where the control plane is supported by lower frequency band such as 800 MHz and 2 GHz and only the user plane is provided by the higher frequency bands such as several tens GHz [IKT12]. In the higher frequency bands, the number of antenna elements drastically increases compared to 2 GHz because size of one antenna element can be miniaturized, and it is expected that Massive MIMO can improve the bit rate and the transmission quality. However, in order to activate Massive MIMO with high performance, a Massive MIMO precoder requires accurate CSI at the transmitter. In addition, Massive MIMO handles an extremely large number of RF and BB circuits, and thus it is more important to compensate for impairments and imbalances of the RF and BB circuits including the antennas.

As the first step of this research, we evaluated performance of 30 Gbps 24x24 MIMO-OFDM eigenmode transmission by link level simulations using channel model based on the Kronecker model. The computer simulations followed the specifications of the 11 GHz band 8x16 MIMO transmission and 24x24 MIMO propagation experiments [SSO+13], [KKG+11]. However, 24x24 MIMO is considered to be not a Massive MIMO but a large-scale MIMO, and thus we evaluate the Massive MIMO transmission using uniform planar array of 256 transmitter antennas. As one of examples for super high bit rate Massive MIMO transmission using the higher frequency bands, we set the carrier frequency and target throughput to 20 GHz and 20 Gbps, respectively. By spatially multiplexing 16 streams with signal bandwidth of 400 MHz, the maximum bit rate achieves 23.5 Gbps. Channel model was based on the Kronecker model including line-of-sight (LOS) and non-line-of-sight (NLOS) components. It is shown that Massive MIMO with 256 antennas can drastically improve the throughput performance by 3D BF effect compared to the typical MIMO with 16 antennas.

Table 9.2 Simulation parameters

Transmission scheme	MIMO-OFDM eigenmode transmission
Carrier frequency	20 GHz
Signal bandwidth	400 MHz
No. of FFT points	4096
No. of active subcarriers	Pilot: 32, data: 2000
No. of antennas	Transmitter: 16, 64, 256 Receiver: 16
No. of data streams	16
Modulation scheme	QPSK, 16QAM, 64QAM (AMC)
Channel coding	Turbo code, R = 1/2, 2/3, 3/4 (AMC)
Antenna array structure	Uniform planar array
Antenna spacing	Transmitter: 2λ, 1λ, 0.5λ. Receiver: 0.5λ.
Angular power spectrum	Laplacian distribution
Average angle (azimuth, zenith)	Departure: (90 deg, 90 deg) Arrival: (90 deg, 90 deg)
Angle spread (azimuth, zenith)	Departure: (5 deg, 5 deg) Arrival: (20 deg, 20 deg)
Channel model	Kronecker model
Fading model	Nakagami-Rice (K = 10 dB), 16-path

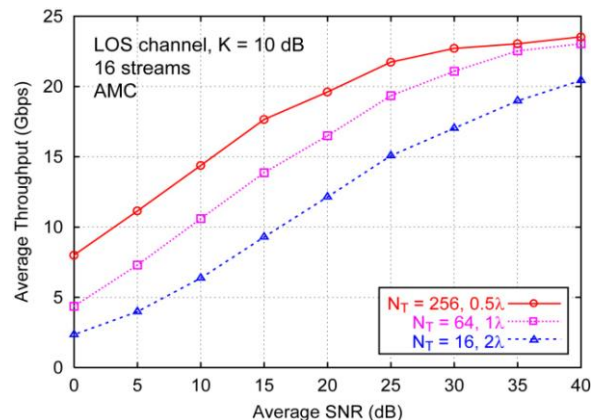


Figure 9.12: Throughput performance of Massive MIMO.

Link level simulations were performed to basically evaluate the feasibility of the 20 Gbps transmission employing the 20 GHz band massive MIMO. The parameters used for the simulations are given in Table 9.2. The MIMO-OFDM eigenmode transmission using ideal CSI is employed as a preceding scheme. The main transmission parameters are same as those in the 10 Gbps experiment [SSO13], and the maximum bit rate reaches 23.5 Gbps according to the parameters set where the modulation and coding scheme is 64QAM with coding rate, R , of $3/4$ in the turbo code. AMC (Adaptive Modulation and Coding) is used ideally. We assume uniform planar array for both the transmitter and receiver antennas, and the Rician factor, K , is assumed to be 10 dB for the Nakagami-Rice fading channel.

Figure 9.12 shows the throughput performance of the Massive MIMO when N_T is set to 16, 64, and 256. In order to keep the entire antenna array size, the TX antenna spacing is changed to 2λ , 1λ , and 0.5λ for each N_T , respectively. The total TX power is constant regardless of the N_T . Compared to $N_T = 16$, $N_T = 64$ obtains the diversity gain in addition to the BF gain. With $N_T = 256$, the additional BF gain can reduce the required SNR to achieve 20 Gbps throughput by 17 dB and 6 dB compared to $N_T = 16$ and 64, respectively.

Finally, in future works, we will analyze performance transmission of Massive MIMO by computer simulation using real channel data that 20 GHz band DOCOMO's Massive MIMO channel sounder will measure in WP1 T1.2.

9.1.7.1 Acronyms

RF	Radio Frequency
BB	BaseBand
LOS	Line-Of-Sight
NLOS	Non-Line-Of-Sight
BF	BeamForming
AMC	Adaptive Modulation and Coding
CSI	Channel State Information

9.1.7.2 References

[NDP13] NTT DOCOMO press releases, "DOCOMO and Tokyo Institute of Technology achieve world's first 10 Gbps packet transmission in outdoor experiment," http://www.nttdocomo.co.jp/english/info/media_center/pr/2013/0227_00.html, Feb. 2013.

[SSO+13] S. Suyama, J. Shen, Y. Oda, H. Suzuki, and K. Fukawa, "11 GHz band 8x16 MIMO-OFDM outdoor transmission experiment for 10 Gbps super high bit rate mobile communications," Proc. IEEE PIMRC2013, Sept. 2013.

[IKT12] H. Ishii, Y. Kishiyama, and H. Takahashi, "A novel architecture for LTE-B: C-plane/U-plane split and Phantom Cell concept," IEEE Globecom Workshops, pp. 624-630, Dec. 2012.

[KKG+11] Y. Konishi, M. Kim, M. Ghoraiishi, J. Takada, S. Suyama, and H. Suzuki, "Channel sounding technique using MIMO software radio architecture," Proc. the 5th EuCAP, pp. 2546-2550, Apr. 2011.

9.1.8 T3.1 TeC.08 Massive MIMO and ultra dense networks

In this work, we study a time-division duplexing (TDD)-based network architecture with the aim of integrating a massive MIMO macro network with a dense layer of small cells (SCs). Due to the large number of SCs, we focus our attention on a distributed, uncoordinated framework, where interference is tackled locally. We note that the TDD assumption is crucial as it does not only enable the base stations (BSs) and SCs to estimate the channels to their intended user equipments (UEs), but also to estimate the covariance matrix of the interfering signals from other cells and network tiers. Due to the uplink-downlink channel reciprocity, this knowledge can be leveraged for precoding the downlink signal partially orthogonal to the dominating subspace of the received interference covariance matrix. We consider a two-tier network consisting of macro BSs wherein each cell is overlaid with a dense deployment of SCs. The BSs and SCs are respectively equipped with N and F antennas. Each BS serves $K=20$ macro user equipments (MUEs), while each SC serves a single small-cell user equipment (SUE). The MUEs and SUEs have only one antenna.

Our baseline scenario is the frequency-division duplexing (FDD) scheme, assuming that each SC has $F=1$ and each BS $N=20$ antennas. We assume that each tier uses half of its bandwidth for UL and DL transmissions. By changing the fraction of the total bandwidth allocated to each tier, we obtain the DL and UL rate-regions as shown by black solid lines in Figure 9.13 and Figure 9.14, respectively. Next, with the same duplexing scheme, we demonstrate the gains of having additional antennas in each tier. To this end, each SC is equipped with $F=4$ and each BS with $N=100$ antennas, while the number of UEs is kept constant. As can be seen from the dashed lines in Figure 9.13 and Figure 9.14, the UL and DL rates of both tiers are significantly improved (SC UL +100 %, SC DL +50 %, macro UL +200 %, macro DL +150 %). Next, we illustrate the gains of TDD in conjunction with the proposed precoding technique. As before, both tiers operate on different frequency bands, but TDD is used instead of FDD to separate UL and DL transmissions. Since channel reciprocity holds in this case within each tier, the UL covariance information can be used for DL precoding to reduce intra-tier interference. The dashed-and-dotted line in Figure 9.13 indicates the rate-region for the TDD scheme, leading to an additional DL sum-rate gain of around 50% in the macro tier and 30% in SC tier. In summary, we believe that a TDD-based heterogeneous network architecture consisting of massive MIMO BSs and SCs is a very attractive candidate for the next generation of cellular networks.

More details and results can be found in [HHt+13a] and [HHt+13b].

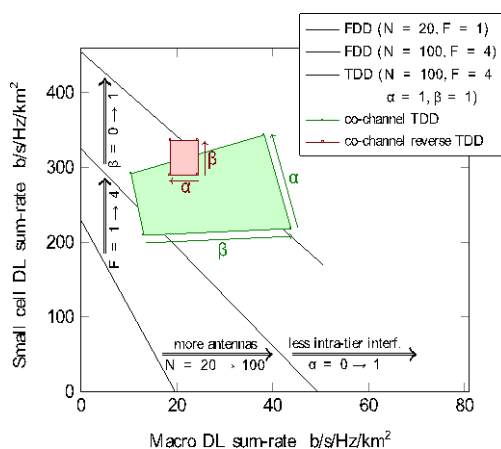


Figure 9.13: Macro-small cell downlink rate region with different duplexing schemes

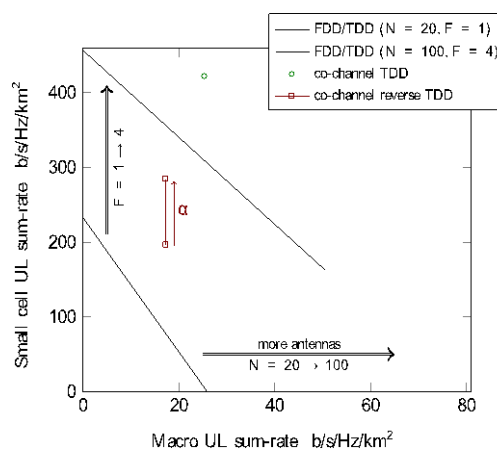


Figure 9.14: Macro-small cell uplink rate region with different duplexing schemes



9.1.8.1 Acronyms

BS	Base Station
DL	Downlink
FDD	Frequency-Division Duplexing
MIMO	Multiple Input Multiple Output
MUE	Macro User Equipment
SC	Small Cell
SUE	Small-Cell User Equipment
TDD	Time-Division Duplexing
UE	User Equipment
UL	Uplink

9.1.8.2 References

[HHt+13a] K. Hosseini, J. Hoydis, S. ten Brink, and M. Debbah, "Massive MIMO and Small Cells: How to Densify Heterogeneous Networks," IEEE International Conference on Communications (ICC), Budapest (Hungary), Jun. 2013.

[HHt+13b] J. Hoydis, K. Hosseini, S. ten Brink, and M. Debbah, "Making Smart Use of Excess Antennas: Massive MIMO, Small Cells, and TDD," Bell Labs Technical Journal, vol. 18, no. 2, pp. 5-21, Sep. 2013.

9.1.9 T3.1 TeC.09 EVD-based channel estimations in MU-Massive-MIMO systems

As presented in [GGA13], for this technology component, we analyzed the MSE performance of the conventional EVD-based and WL channel estimations in multi-cell MU-Massive-MIMO systems. The closed-form MSE characterized two main sources of errors affecting both channel estimates, and quantitatively demonstrated the superiority of the WL algorithm. In regard to the error from the propagation vectors between different users not being perfectly orthogonal, the WL approach makes the augmented channel vectors more orthogonalized, hence decreases the corresponding MSE to one half of the EVD-based one. On the other hand, the WL scheme uses real representation of the received vectors to reduce the inherent phase ambiguity to a sign ambiguity which is much easier to estimate based on the same training process, thus resulting in a smaller MSE which will facilitate a higher user throughput (by alleviating pilot contamination) and lower error rate (by reducing the MSE of channel estimation). Therefore, the WL channel estimate should be therefore preferred in MU-Massive-MIMO systems.

In the simulation, we consider a multi-cell MU-Massive-MIMO system of $L=3$ cells and $K=3$ users in each cell. All users transmit BPSK data samples in the same time-frequency to the BSs. We focus on the MSE performance of the 1-st user in cell 1 for both channel estimations in training case. The path-loss plus large-scale fading coefficients of cell 1 are given in [GGA13]. We use only 1 pilot symbol per user to resolve the phase/sign ambiguity and minimize the pilot contamination among cells. Our numerical results are obtained by averaging over independent channel realizations.

As shown in Figure 9.15, for fixed N the simulated and computed MSE of both channel estimates decrease drastically when M grows from 100 to 300 indicating that the imperfect orthogonality between the channel vectors is the main factor which limits the MSE performance in finite M regime; while for fixed M , the MSE of both estimates become smaller as N increases which reflects exactly the impact of using sample-based covariance matrix. As M, N go to infinity, the numerical outcomes converge as expected to the analytical results. Moreover, there is a prominent MSE gain in the WL estimation comparing to the EVD-based one throughout the simulation, which verifies the advantage of WL method.

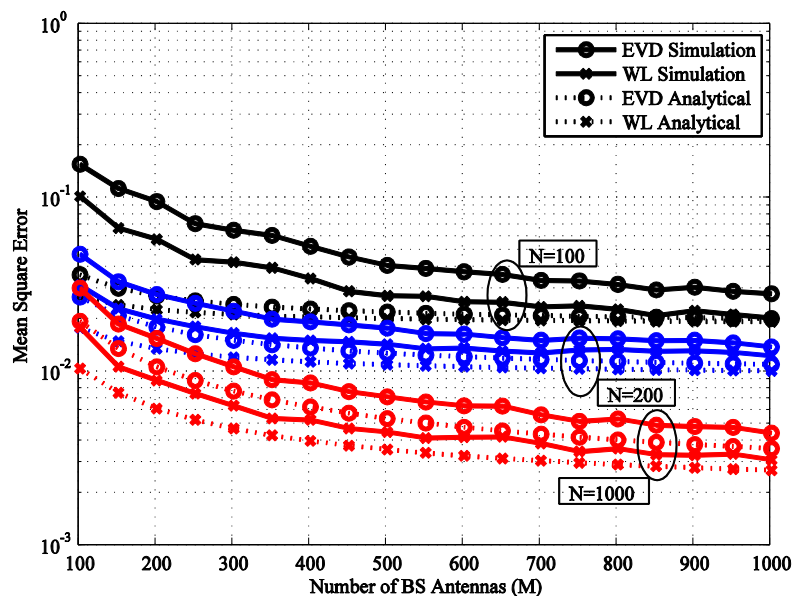


Figure 9.15 MSE performance vs. number of BS antennas.

9.1.9.1 Acronyms

MSE Mean square error



EVD Eigenvalue decomposition
WL Widely linear
BPSK Binary phase shift keying

9.1.9.2 References

[GGA13] K. Guo, Y. Guo, and G. Ascheid, "On the Performance of EVD-Based Channel Estimations in MU-Massive-MIMO Systems," in Proc. IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), pp. 1376-1380, Sep. 2013.

9.1.10 T3.1 TeC.10 Decentralized coordinated transceiver design with large antenna arrays

The problem of interest here is decoupling the subproblems at different BSs for a minimum power beamforming by utilizing a large dimension approximation for ICI terms as the coupling term which results a simplified near optimal algorithm with smaller exchange rate and processing load compared to the optimal solution.

The cellular system consists of N_B BSs and K single antenna users; each BS has N_T transmitting antennas. Users allocated to BS_b are in set U_b . The signal for user k consists of the desired signal, intra-cell and inter-cell. Assuming $f_{b,k}$ as transmit beamformer, we solve following optimization problem :

$$\begin{aligned} & \text{Min} \sum_{b \in B} \sum_{k \in U_b} |w_{b,k}^H h_{b,k}|^2 \\ & \text{subject to} \frac{|w_{b,k}^H h_{b,k}|^2}{\sigma^2 + \sum_{l \in U_{b_k} \setminus k} |w_{b,l}^H h_{b,l}|^2 + \sum_{b \neq b_k} \varepsilon_{b,k}^2} \geq \gamma_k \quad \forall k \in U, b \in B \\ & \sum_{l \in U_b} |w_{b,l}^H h_{b,l}|^2 \leq \varepsilon_{b,k}^2 \quad \forall k \neq U_b, b \in B \end{aligned}$$

where the optimization variables are the beamformers $w_{b,k}$ and the inter-cell interference levels $\varepsilon_{b,k}$. The channel between BS b and user k is denoted as $h_{b,k}$. Following the same logic as in [TPK11], inter-cell interference (ICI) is considered as the principal coupling parameter among BSs. We show that a large dimension approximation for ICI term based on statistics of the channels can be expressed as follow when there is no correlation among channel vectors entries,

$$\varepsilon_{b,k}^2 \approx \sum_{l \in U_b} \sqrt{\delta_{b,l}} \frac{1}{N_T} \frac{a_{b_l,k}^2 a_{b_l,l}^2 m_{B_l}(-1)}{\mu_{b_l,l}^2 \mu_{b_l,k}^2}, \quad \mu_{b_l,i} = \lambda_{i,j} a_{b_l,i}^2 m_{B_l}(-1)$$

This formula express an approximation for optimal $\varepsilon_{b,k}^2$, downlink interference from BS_b to user k , based on an approximately optimal dual uplink powers $\lambda_{i,j}$, downlink power loading parameters $\delta_{b,l}$ and statistics of the channels defined by pathlosses $a_{b_l,i}^2$ and $m_{B_l}(-1)$ which is

the Stieltjes transform of $\left(\sum_{(m,l)} \lambda_{m,l} h_{i,m,l} h_{i,m,l}^H \right)$ evaluated at $z=-1$. The approximate optimal uplink and downlink powers can be calculated by using the algorithm introduced in reference [LHDA10]. Once the approximate ICI is calculated, the subproblems at different BSs can be solved independently as the statistics of the channel remain fixed for several intervals even for a fast fading scenario. This algorithm provides reduction in exchange rate and processing load with a small performance loss compared to the optimal solution, however, this results are limited to the case without correlation which restricts its applicability. Therefore in next step we

consider a more general case where, $h_{b,k} = C_{b,k}^{\frac{1}{2}} g_{b,k}$, $C_{b,k}$ is the correlation matrix of user k and $g_{b,k}$ is a vector with i.i.d complex entries with variance $\frac{1}{N_T}$. This per-user channel correlation model can be applied to various propagation environments.

The algorithm developed satisfies the target SINRs for all users; however, the error in approximations results a higher transmit power at BSs. In order to evaluate the difference between the optimal transmit power and the power resulted from the approximated algorithm, an extensive multi-cell simulation study is carried out. A network with 7 cells is considered and users are scattered on the coverage area of the network, in a way that each cell contains 4 users. The users are dropped randomly for each trial and in total 1000 user drops are used for calculating the average transmit power.

Figure 9.16 illustrate the transmit powers versus the number of antennas for 0dB and 10dB SINR target, respectively. The fading characteristic per antenna is i.i.d.. It is clear that the gap between the approximate and optimal algorithm, denoted as Second Order Cone Programming (SOCP) [TPK11], diminishes as the number of antennas increases. When the number of antennas is equal to 28 the gap is less than 0.5 dB which indicates that the approximate algorithm provides a good solution for the practical scenarios with a limited number of antennas. The gap for the case with 0dB SINR in Figure 9.16 does not exceed 1dB even when the number of antennas is smaller than 28, however, for the case with 10dB SINR target, the approximated case becomes infeasible.

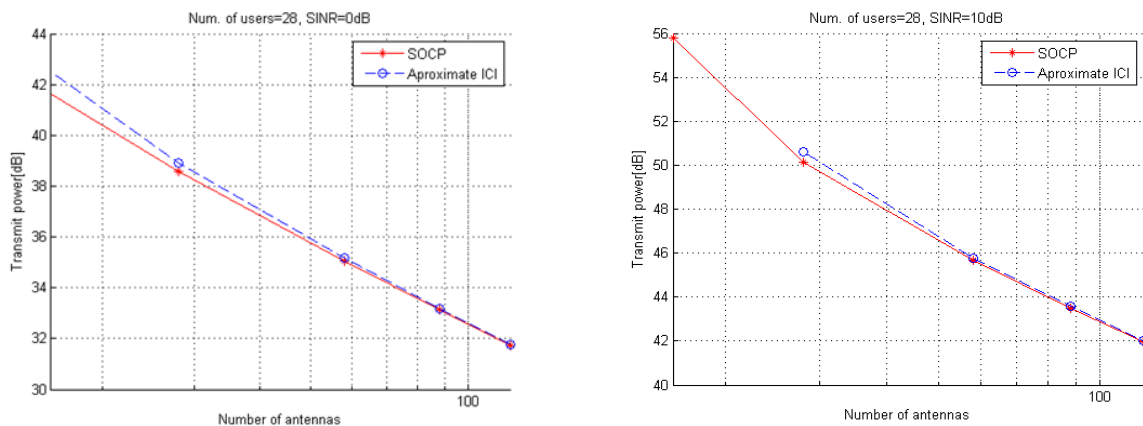


Figure 9.16 Required transmit power for 0 and 10 dB SINR target.

9.1.10.1 Acronyms

- ICI Inter-cell interference
- SOCP Second Order Cone Programming

9.1.10.2 References

[TPK11] A. Tölli, H. Pennanen, and P. Komulainen, “Decentralized Minimum Power Multi-cell Beamforming with Limited Backhaul Signalling,” *IEEE Trans. on Wireless Comm.*, vol. 10, no. 2, pp. 570 - 580, February 2011.

[LHDA10] S. Lakshminarayana, J. Hoydis, M. Debbah, M. Assaad, “Asymptotic analysis of distributed multi-cell beamforming,” *IEEE PIMRC 2010, Istanbul, Turkey*, pp 2105-2110, 26-29 September 2010.

[DY10] H. Dahrouj, W. Yu, “Coordinated beamforming for the multicell multiantenna wireless system,” *IEEE Transactions on Wireless Communications* 9, pp. 1748–1759, 2010

[WCMD12] S. Wagner, R. Couillet, D. Merouane, D. T. M. Slock, “Large System Analysis of Linear Precoding in Correlated MISO Broadcast Channels under Limited Feedback,” *IEEE Trans. Inf. Theory*, vol. 58, no. 7, pp. 4509 - 4537, Jul. 2012.

9.1.11 T3.1 TeC.11 Massive SDMA with a LSAS exploiting elevation and azimuth beamforming

This technology component aims on downlink in a TDD system where we assume a “large” 8x16 rectangular active antenna array when using the acronym “LSAS”. In contrast to the term “massive” MIMO which inherently considers that the number of antennas N_t is much larger than the number of user N_k in the systems, i. e. $N_t \gg N_k$, we introduce the term “massive SDMA” considering a LSAS and the regime $N_t \approx N_k$. With this the sum spectral efficiency of the system can be increased tremendously and it also covers scenarios from Deliverable D1.1 [METIS11] assuming a much denser distribution of users or devices compared to current systems.

Further assumptions in this work can be seen in the overview table of the core document of T3.1 TeC 11. To model the channel we highlight the use of the QUADRIGA [JRB+13] channel model which is an extension of SCME where a 3-dimensional modelling approach is used for geometric polarization propagation of co-/cross-polarized antenna arrays, path-loss distance and the angle of arrival/departure in elevation as well as azimuth. Also the placement of scatterers is in 3D coordinates.

ZF precoding is considered in combination with either sum-rate maximizing semi-orthogonal user selection (SUS) henceforth called PBZF or simple round robin (RR) grouping at the transmitter. By increasing the number of users in the system, we observe a sum SE gain exploiting user diversity for PBZF. The drawback is that the number of simultaneously served MSs is approximately constant. Using instead RR grouping the SE performance is degrading increasing the number of MSs. This is due to the reduction of signal power by an equal spread over more streams and an imbalance between intra and inter-cell interference (ICI). This means that cancelling intra-cell interference to zero sacrificing signal power is not necessary in the presence of ICI. The solution for this is that information about the interference situation experienced by MSs needs to be fed back to the BS. Then regularized ZF (RZF) precoding can be used where the idea is that inter-stream interference is only reduced to the same level as the already existing ICI. To keep the additional feedback overhead low we propose to use a wideband power value per MS which can be obtained by

$$P_{reg,k} = \frac{1}{N_{RB}} \sum_{i=1}^{N_{RB}} \text{trace}(\mathbf{Z}_{k,i}),$$

where N_{RB} is the number of RBs and $\mathbf{Z}_{k,i}$ the inter-sector covariance plus noise matrix of MS k and RB i . With this very low additional feedback overhead a gain of 154 % in sum SE can be achieved for RR grouping at 120 MS and still 16 % with PBZF, shown in Figure 9.17.

The second achievement we want to highlight is on the per antenna power constraint (PAPC) included in present systems. Assuming 43 dBm sum power for the LSAS BS which is in LTE the same as for a 2 antenna BSs and 18 MHz bandwidth this leads to a spectral power density of 0.2 W per RB. Mapped to 128 antennas this is a PAPC of 1.6 mW which relaxes the requirements for amplifiers tremendously compared to current BSs. Therefore, we propose to use only a sum or pool power constraint. The gain which can be obtained by using a pool instead of a per antenna power constraint is 20 and 30% for RR and PBZF respectively, shown in Figure 9.18.

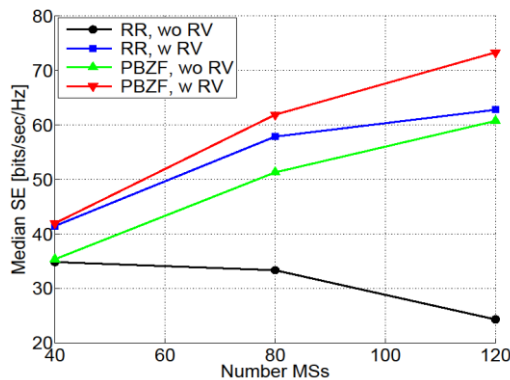


Figure 9.17: Median sum SE over MSs for RR and PBZF grouping with and without interference power as regularization factor.

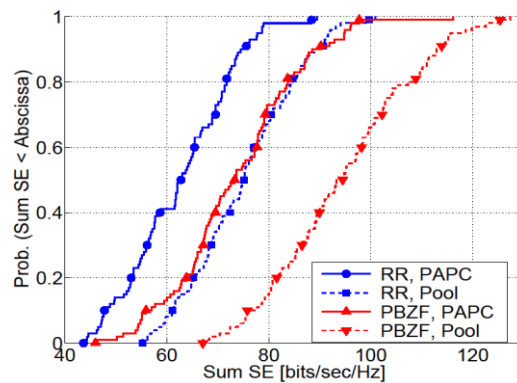


Figure 9.18: Sum SE at 120 MSs for RR/PBZF with per antenna power constraint and pool power constraint.

9.1.11.1 Acronyms

BS	Base Station
ICI	Inter Cell Interference
LSAS	Large Scale Antenna System
MIMO	Multiple Input Multiple Output
MS	Mobile Station
PAPC	Per Antenna Power Constraint
PBZF	Projection Based Zero Forcing
QUADRIGA	QUAsi Deterministic Radlo channel GenerAtor
RR	Round Robin
SCME	Spatial Channel Model Extended.
SDMA	Spatial Division Multiple Access
SE	Spectral efficiency
SUS	Semi-orthogonal User Selection
TDD	Time Division Duplex
WINNER	Wireless world INitiative NEw Radio
ZF	Zero Forcing

9.1.11.2 References

[METIS11] METIS consortium, "D1.1 – Scenarios, requirements and KPIs for 5G mobile and wireless system," project report, Apr. 2013.

[JRB+13] S. Jaeckel, L. Raschkowski, K. Börner, L. Thiele, F. Burkhardt, E. Eberlein, "Quasi Deterministic Radio Channel Generator User Manual and Documentation," June 2013

9.2 Preliminary Results for Task 3.2

9.2.1 T3.2 TeC.01 Multi-node resource allocation under imperfect feedback and backhaul channels

In this work, the performance of different CoMP downlink transmission schemes is evaluated with both predicted and outdated channel state information (CSI) cases, considering the effects of feedback and backhaul latency, user mobility and feedback errors. To this end, three network architectures, namely the centralized, semi-distributed and fully-distributed CoMP architectures [MLP+14] are considered, which introduce different transmission latencies and feedback errors. We consider three different CoMP transmission schemes, i.e., zero-forcing coherent joint transmission with optimal power allocation (ZF-OPA), non-coherent joint transmission with binary power control (NCJT-BPC), and coordinated scheduling with binary power control (CS-BPC), with respect to different sets of user starting locations. A single-cell transmission scheme without BS coordination, denoted as SC, is used as baseline. The feedback and data processing delay is assumed to be 5 ms. The backhaul latency is 10 ms. More detailed simulation parameters can be found in [LPA+12].

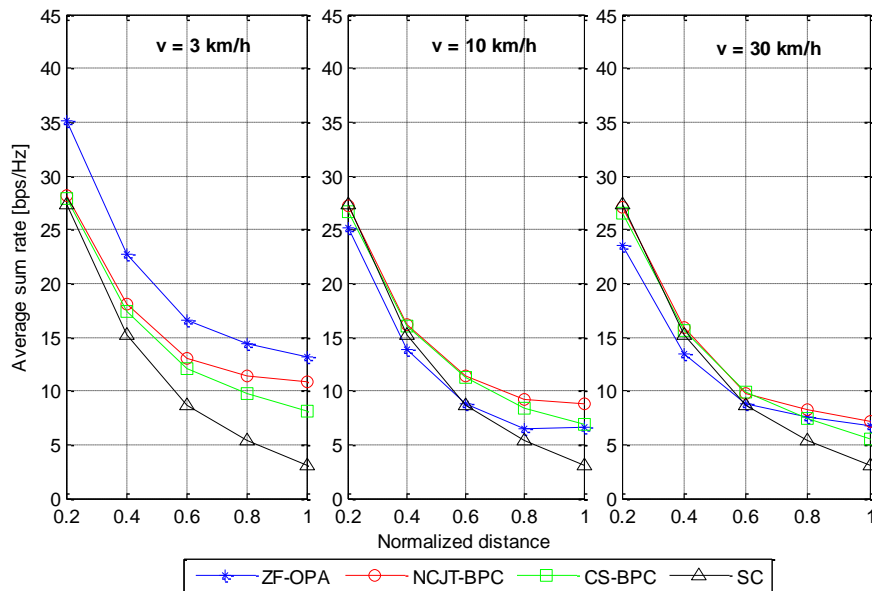


Figure 9.19: Average sum rate vs. normalized distance under the centralized architecture with predicted CSI

The performance of different CoMP transmission schemes under the centralized architecture is shown in Figure 9.19 considering different user motilities. We can observe that

1. The quality of CSI available at the CU affects the performance of the coherent joint transmission scheme substantially; while the non-coherent joint transmission and coordinated scheduling schemes are more robust to the channel uncertainty.
2. Depending on the user location and user mobility, the system should switch between CoMP schemes to improve the system sum rate.

Other important observations obtained by our numerical results include:

3. The fully-distributed network architecture is more tolerant to outdated CSI; while channel prediction is needed for the centralized and semi-distributed architectures in order to improve the sum rate, especially for the coherent joint transmission scheme.
4. For each CoMP transmission scheme with predicted CSI, the performance achieved by the fully-distributed architecture is the worst compared to the centralized and semi-distributed ones.



9.2.1.1 Acronyms

BPC	Binary Power Control
CoMP	Coordinated Multi-Point Transmission
CS	Coordinated Scheduling
CSI	Channel State Information
CU	Central Unit
NCJT	Non-coherent joint transmission
OPA	Optimal Power Allocation
SC	Single Cell
ZF	Zero Forcing

9.2.1.2 References

[MLP+14] Z. Mayer, J. Li, A. Papadogiannis, and T. Svensson, "On the impact of control channel reliability on coordinated multi-point transmission," EURASIP Journal on Wireless Communications and Networking 2014, Feb. 2014.

[LPA+12] J. Li, A. Papadogiannis, R. Apelfröjd, T. Svensson, and M. Sternad, "Performance analysis of coordinated multi-point transmission schemes with imperfect CSI," in Proc. IEEE PIMRC'12, Sydney, Australia, Sept. 2012.

9.2.2 T3.2 TeC.02 Exploiting temporal channel correlation to reduce feedback in CoMP scheme

In this work, we are interested in CoMP scheme with limited feedback taking into account the time correlation of the channel in slow fading environment. We consider CoMP system model with and without outer-cell interference, which means the cells outside the clusters. The feedback framework used is the feedback resource reusing scheme, where the receiver feeds back its beamforming index at every n^{th} channel instance. This feedback update period is determined proportional to the amount of channel correlation. We derive the optimization problem which determines the optimal feedback updating period that keeps the performance of the CoMP system using a conventional feedback framework at every channel instance. This optimal feedback period can be exploited as the time spent on the exchange of the CSI (and or data) required for the CoMP systems.

The objective is to derive the optimal feedback period n that insure the same total throughput as the conventional scheme A, for that we calculate the the average SINR loss at the m th channel instance between Scheme B and Scheme A given by:

$$D_m^{\text{SINR}} = \mathbb{E}[SINR_{\text{SchemeB}} - SINR_{\text{SchemeA}}]$$

The optimization problem of finding the updating period of Scheme B guaranteeing greater SINR gain than Scheme A is formulated by finding the optimal channel index m^{SINR} verifying

$$m^{\text{SINR}} = \underset{m \geq 0}{\text{argmin}} D_m^{\text{SINR}}$$

$$s.t. D_m^{\text{SINR}} \geq 0.$$

Solving this optimization problem is equivalent to find maximum m such that $D_m^{\text{SINR}} \geq 0$. Then, the feedback updating period is $n^{\text{SINR}} = m^{\text{SINR}} + 1$. Manipulating the condition on D_m^{SINR} yields a bound on m , and the solution is :

$$m^{\text{SINR}} = \left\lfloor \log_{\alpha^2} \left(\frac{\text{SI}(N_1) - \text{ASB}}{\text{SI}(N_2) - \text{ASB}} \right) \right\rfloor_+$$

where

$$\text{ASB} = \frac{1}{2} - \frac{1}{\sqrt{\pi}} \sum_{j=0}^{\infty} \sum_{k=0}^{2j+1} \sum_{l=0}^k \frac{(-1)^{3j+k+1} (2j)! \mu_w^{2j+1-k}}{(\sqrt{2\sigma_w^2})^{2j+1} j! l! (2j+1-k)! (k-l)! (Mn_t - 1)! (k+1)!} \frac{(Mn_t + l - 1)! (Pn_t)^l}{(k-l)! (Mn_t - 1)! (k+1)!}$$

$$\text{SI}(N_1) = 1 - \sum_{l=0}^{N_1} \sum_{j_1, j_2, \dots, j_J} \binom{l}{j_1, j_2, \dots, j_J} \frac{N_1! (-1)^l}{l! (N_1 - l)!} \times \left[\frac{1}{(Pn_t)^{Mn_t} (Mn_t - 1)!} \right]^l I_1(\mathbf{v}, \boldsymbol{\xi}, l, j_1, \dots, j_J)$$

and $\text{SI}(N_2)$ is found by substituting the codebook size N_1 used in scheme A into $\text{SI}(N_1)$ by the codebook size N_2 of the scheme B. See [OK13] for further details.

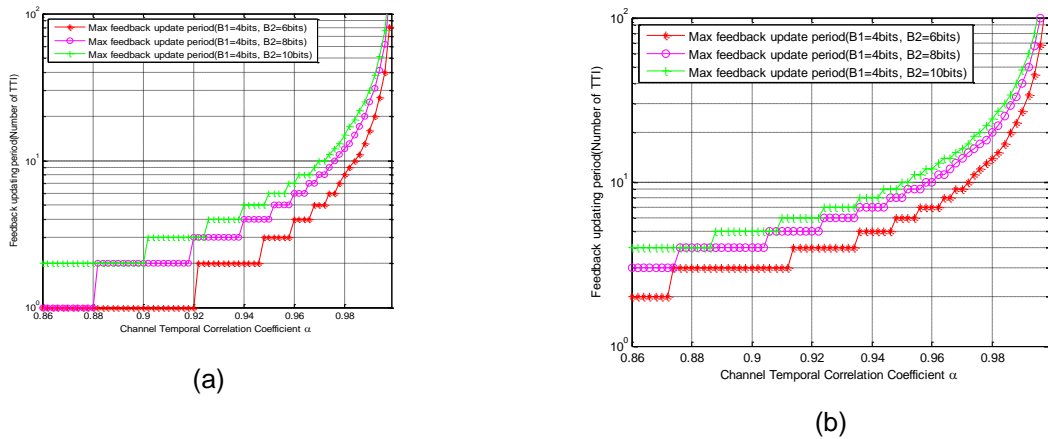


Figure 9.20: Maximum Feedback Updating Period of Scheme B for $B_1 = 4$ bits and $B_2 = 6, 8, 10$ bits when considering other-cell interference.

Figure 9.20 (a) shows the updating feedback period for the scheme without considering the pathloss, beside the Figure 9.20 (b) represents the updating feedback period for the scheme with independent pathloss from the Ue to each transmit node. We can conclude from Figure 9.20 that whenever B_2 increases, i.e. the feedback is finer, the feedback updating period can be extended as long as it guarantees an improved performance over Scheme A.

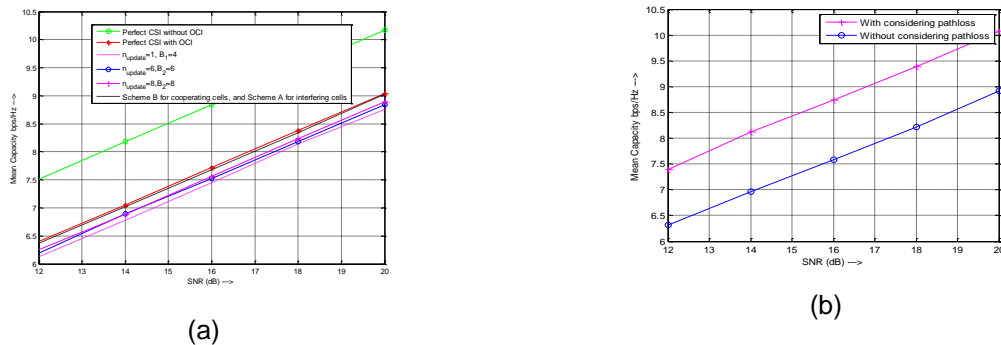


Figure 9.21: Throughput performance of Scheme A (4 bits/channel use) and Scheme B (1 bits/channel use). User speed 15km/h.

In Figure 9.21, we plot the achievable capacity with full CSI with and without other cell interference (OCI) for system with and without path loss respectively in Figure 9.21 (a) and Figure 9.21 (b). We can conclude that the pathloss increase the duration of the updating feedback period.

9.2.2.1 Acronyms

- CoMP Coordinate Multi Point
- CSI Channel State Information
- OCI Other Cell Interference
- SINR Signal to Interference and Noise Ratio

9.2.2.2 References

[OK13] A.Ossman, H.Khanfir, "Optimal Feedback Updating Period for Coordinated Multi-Point Transmission Schemes," IEEE PIMRC 2013, London, UK, pp. 2281 – 2285, Sept. 2013

9.2.3 T3.2 TeC.02b DoF and net DoF of recent schemes for the MIMO IC and BC with delayed CSIT and finite coherence time

In this TeC we focus on the theoretical analysis of the DoF and net DoF of recent schemes for the MIMO IC and BC with DCSIT and finite coherence time and propose new schemes more robust to feedback delays.

First a new metric was defined in order to fairly evaluate the effect of feedback delay by measuring the degrees of freedom (DoF) available taking into account both feedback and training overheads. This approach allowed us to find interesting techniques that efficiently deals with feedback delay. Among them is one developed for the MISO broadcast channel [LH12] that is singled out as it was the very first solution that allowed preserving the optimal DoF for small feedback delay.

Noticing its potential in [LSY13a] we then extend this technique to multiple cell configurations and to MIMO configurations. More precisely, in MIMO configurations we make use of the multiple antennas at receiver to preserve the optimal DoF for longer feedback delay than with single antenna receivers in [LSY13b].

Going from MISO to MIMO (both in BC and IC) allows to preserve the sum DoF for feedback delay up to $1/(N_t/N_t+1)=N_r/(N_t+N_r)$ of the channel coherence time. Where N_t and N_r are respectively the number of transmit and receive antennas. The DoF is the prelog of the sum rate, also called multiplexing gain.

Longer feedback delay can be dealt with by doing time sharing between Space Time Interference Alignment (STIA) and any techniques that rely only on delayed CSIT or on no CSIT at all such as Maddah-Ali-Tse (MAT) scheme from [MT10] or TDMA.

In Figure 9.22 lower and upper bounds on the DoF region for $N_t = 8$ and different N_r as a function of the ratio feedback delay/channel coherence time are given for the case of time sharing between STIA and MAT. We observe that increasing the number of receive antennas allows to win on both sides, preserving the full sum DoF on a wider range of and also increasing the DoF reached by MAT.

Similar results are obtained in the MIMO IC.

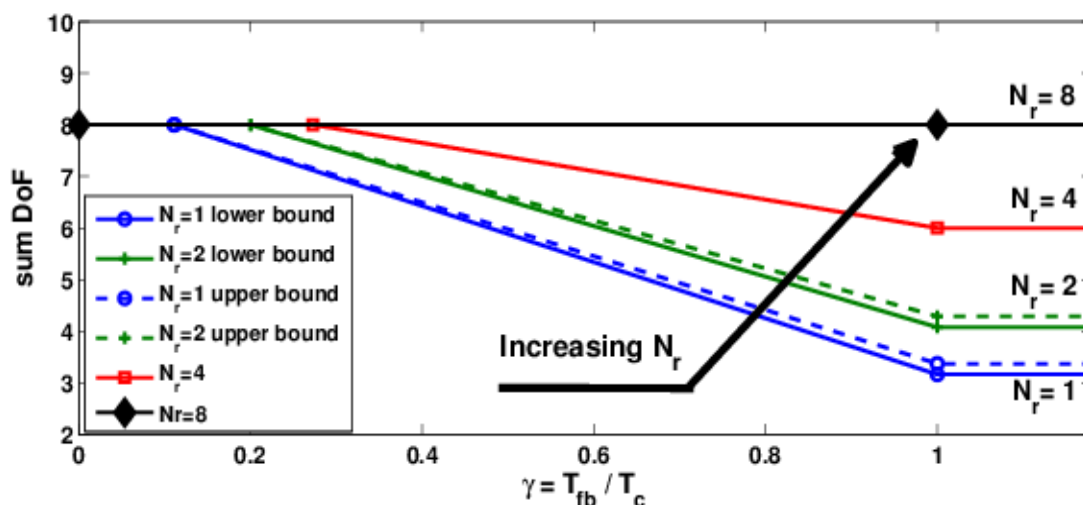


Figure 9.22: Time sharing between STIA and MAT in the BC for $N_t=8$.

9.2.3.1 Acronyms

BC Broadcast Channel



CSIT	Channel State Information at the Transmitter
DCSIT	Delayed CSIT
DoF	Degrees of Freedom
IC	Interference Channel
LTE	Long Term Evolution
MAT	Maddah-Ali-Tse scheme
STIA	Space Time Interference Alignment
TDMA	Time Division Multiple Access

9.2.3.2 References

[MT10] M. Maddah-Ali and D. Tse, "Completely stale transmitter channel state information is still very useful," in Proc. Allerton, Monticello, IL, USA, Oct. 2010.

[LH12] N. Lee and R. W. Heath Jr., "Not too delayed CSIT achieves the optimal degrees of freedom," in Proc. Allerton, Monticello, IL, USA, Aug. 2012.

[LSY13a] Y. Lejosne, D. Slock, and Y. Yuan-Wu, "Net degrees of freedom of recent schemes for the MISO BC with delayed CSIT and finite coherence time," in Proc. WCNC, Shanghai, China, Apr. 2013.

[LSY13b] Y. Lejosne, D. Slock, and Y. Yuan-Wu, "Space Time Interference Alignment Scheme for the MISO BC and IS with Delayed CSIT and Finite Coherence Time", in Proc. ICASSP, Vancouver, Canada, May 2013

9.2.4 T3.2 TeC.03 Distributed precoding in multi-cell multi-antenna systems with data sharing

This technology component is a multi-cell downlink cooperation scheme, which utilizes the possibility for smart data sharing envisioned for future networks (e.g., by caching of video content, or by prediction algorithms). The goal is to increase the capacity by adaptively mitigating the multi-cell and multi-user interference using local channel knowledge only. Thereby, the method abstains from fast and frequent channel-based information exchange via the backhaul links, as these present bottleneck factors especially in ultra-dense deployments. The particular focus of the work is on precoding algorithms, which increase the number of active users that can be served in an (nearly) interference-free manner.

An illustrative performance result is shown in Figure 9.23. In the simulated scenario, an isolated cluster of two single-antenna base stations is cooperatively serving two single antenna users on one subcarrier. Notice that most of the cooperating approaches based on local channel knowledge would not be able to support more than one user in this simple setup. The compared schemes are: DIA (Destructive Interference Addition) – the proposed approach for distributed interference-free transmission, DIA-UPC (DIA with Uncoordinated Power Control) – a variant of DIA with fully distributed power scaling, CMP (Coordinated Multi-cell Precoder) – the best reference solution for the scenario of interest, JZF (Joint Zero-Forcing) – a fully cooperative solution from the literature with ZF linear precoding and optimized power control used as an indicator of the optimal curve slope in high SNR regime. It can be seen that in this scenario, the proposed DIA algorithm extracts the maximum degrees of freedom (cf. the slopes of the curves in the high SNR regime), and that its performance is quite close to the one from the JZF approach. DIA-UPC is a practical approach for low and medium SNR regimes, as it relaxes the interference nulling condition in the DIA algorithm. Both proposed approaches outperform significantly the CMP strategy in medium and high SNR regimes.

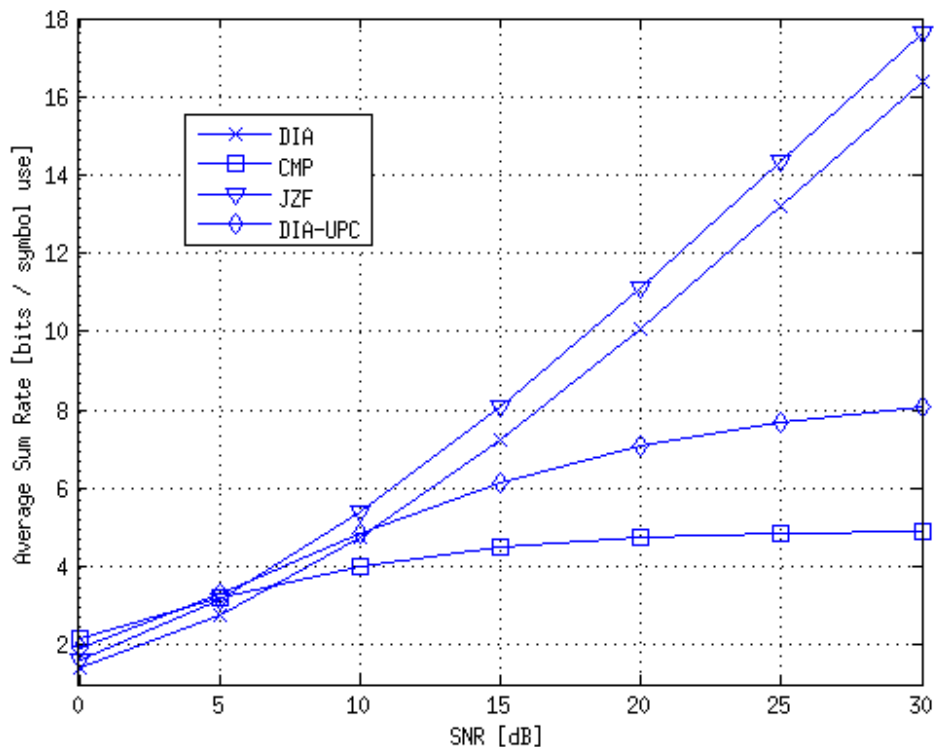


Figure 9.23: Average spectral efficiency (sum rate) for the system with two single-antenna base stations and two single-antenna users.



9.2.4.1 Acronyms

CMP	Coordinated Multi-cell Precoder
DIA	Destructive Interference Addition
JZF	Joint Zero-Forcing
SNR	Signal to Noise Ratio
UPC	Uncoordinated Power Control

9.2.5 T3.2 TeC.04 Real world Interference Alignment

Interference management in cellular networks is a well known issue which limits the performance of the cellular networks. Interference Alignment (IA) is one of the solutions to manage the interference efficiently by using “align” and “suppression” strategy. In cellular multi-antenna, multi-user (MU-MIMO) systems the users are suffered not only by the inter-cell interference (ICI) but also the intra-cell (multi-user) interference (MUI). The contribution in [AW13] addresses the issue of MUI and the applicability of IA to deal with both types of interferences in the system. The idea in [AW13] is to use stale ICI information for the alignment with MUI. The ICI from the last transmission is still useful and can be used to design the transmit precoding for the current transmission. For this purpose, the BS requires only the local information i.e. no inter-BS coordination is required. Each user sends the required information only to its serving BS.

We consider an OFDM based closed loop downlink multiuser MIMO cellular system which consists of multiple cells each equipped with M transmit antennas. Each cell is serving R active UEs ($R \geq M$). Each UE is equipped with N antennas. Only K out of R UEs are selected simultaneously on the same time-frequency resource for transmission. In order to limit the search space, we assume $K=2$ (pair selection) and single stream transmission for each UE. We assume a block fading channel in time and frequency over an allocated OFDM physical resource block. The serving cell designs the Multi-user Inter-Cell Interference Alignment (MUICIA) based transmit precoding vectors for the two selected users as given in [AW13]. Interference rejection combining receiver algorithm is used at the receiver side. Please refer to [AW13] for details of transceiver design.

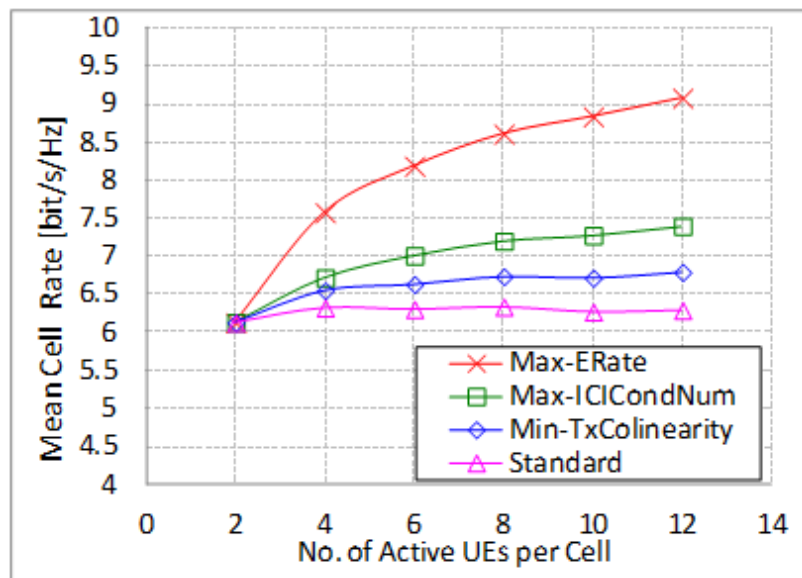


Figure 9.24: Spectral efficiency with respect to the number of active UEs per cell

The channel realizations are generated by using spatial channel model. Please refer to [3GPPT36814] and references there in for details of the model and simulation parameters. For the simulation results, here we have used a site with three sectors. Each sector corresponds to a cell with unique cell ID. The total frequency bandwidth is divided into ($B=50$) physical resource blocks (PRB) [3GPPT36814]. Each PRB contains ($W=12$) consecutive subcarriers with a frequency spacing of 15kHz. With the user speed of 3 km/h, we have slow time variant and nearly time-frequency flat channels within a single PRB. However, we have frequency diversity due to high number of PRBs with in a TTI. In each TTI, the serving cell applies the selection criteria to individual PRBs. With the resource structure mentioned [3GPPT36814], we have the possibility of ‘B’ different pair selections within a TTI if the number of active users is very high. The output SINR after the receive-processing is evaluated



for each PRB as given in [AW13]. This output SINR is then used to calculate the mean cell rates in bits/sec/Hz. Please refer to [AW13] for further details. We have selected an input average SINR of the UEs as 8 dB. In a cellular network this value lies between 6 to 10 dB.

Figure 9.24 presents the results with MUICIA transmit precoding for different user selection methods. It is clear that the cell rate performance enhances with the increase in the number of UEs. Notice that our proposed methods provide considerable gains in the performance as compared to the standard selection method. If we look at the performance with 12 UEs then we have almost 20% gains with the *Max-ICICondNum* over the standard method, whereas the *Min-TxColinearty* provides only 10% gains over the standard method. This is because the condition number based selection supports the alignment based precoding by maximizing the alignment gain. In fact, we get two-fold gains with *Max-ICICondNum* selection method. Firstly, the BS is able to perfectly align the MUI and ICI for the UEs which have high condition numbers. Secondly, the corresponding receivers are able to successfully suppress the interference subspace. The selection with *Max-Rate* outperforms all other methods and provides around 20% gains over *Max-ICICondNum* and 45% gains over the standard user selection method. However, *Max-Rate* is a computationally complex method and it is based on exhaustive search which requires high processing power. In comparison, *Max-ICICondNum* is very simple and it requires only the sorting of the UEs for selection. Therefore, it can be seen as a good trade-off between computational complexity and system performance.

9.2.5.1 Acronyms

BS	Base Station
MUICIA	Multi-user Inter-Cell Interference Alignment
IA	Interference Alignment
MUI	Multi-user Interference
ICI	Inter-Cell Interference
UE	User Equipment
OFDM	Orthogonal Frequency Division Multiplexing
MIMO	Multiple Input Multiple Output
MU	Multi-user
MU-MIMO	Multi-user MIMO
PRB	Physical Resource Block

9.2.5.2 References

[AW13] D. Aziz, A. Weber: "Transmit precoding based on outdated interference alignment for two users multi cell MIMO system," Proceedings of IEEE ICNC, San Diego, USA, Jan 2013.

[3GPPTR36814] 3GPP, "Further Advancements for E-UTRA - Physical Layer Aspects," TR 36.814, V 9.0.0, March 2010

9.2.6 T3.2 TeC.05 Semi-distributed IA algorithm for MIMO-IC channel with power control convergence speed up

We consider a system of K APs equipped with M_T transmit antennas and K users equipped with M_R receive antennas. Each Access Point (AP) is paired with a single user in a one to one mapping. Without loss of generality, we assume that both of them has index k . Each AP interferes with all the receivers it is not paired with. The system represents, as such, the K -user MIMO interference channel. The channels between the different links are considered to be narrow-band where each link is static for the duration of a transmission but may change between successive transmissions. This is the block-fading model, where all the links in the network are constant for the period of transmission, creating a tractable approximation to more realistic continuous-fading models. Finally, local and perfect channel knowledge is assumed at each of the transmit and receive nodes.

The transmitted signal $\mathbf{x}_k \in X^{M_T \times 1}$ from AP k to its attached user is given by $\mathbf{x}_k = \mathbf{V}_k \mathbf{s}_k$, where $\mathbf{V}_k \in \mathbb{C}^{M_T \times d_k}$ is a pre-coding matrix applied to the streams vector intended to user k , d_k , is the number of streams transmitted on link k and $\mathbf{s}_k \in X^{d_k \times 1}$ is the vector containing the data symbols intended to user k . At the reception, each user k decorrelates the received signal by applying the decorrelation matrix $\mathbf{U}_k \in \mathbb{C}^{d_k \times M_R}$. The aim is to design \mathbf{V}_k and \mathbf{U}_k to ensure a set of SINRs $\gamma_1^1, \gamma_1^2, \dots, \gamma_1^{d_1}, \dots, \gamma_K^1, \gamma_K^2, \dots, \gamma_K^{d_K}$ at all the streams of all the links.

The coordination is based on a power optimization process: the APs run the distributed algorithm to determine the filters at BS and UE for a given set of target SINRs assuming equal power allocation between the different streams. After every iteration, the APs feed back some control information to a Central Unit (CU). Based on these information, the CU checks whether there exists an optimal power allocation that enables to reach the chosen target SINRs and therefore there is no need to continue to iterate. The power allocation determination is based on an existing algorithm in [HJF+10]. The algorithm enables as such to save the number of iterations and consequently to reduce the implementation complexity.

The simulations are considered for the case of the 3-user 2×2 MIMO IC. For the semi-distributed coordination algorithm, the chosen target SINRs are the average SNR of every link. However other target SINR combinations can be adopted.

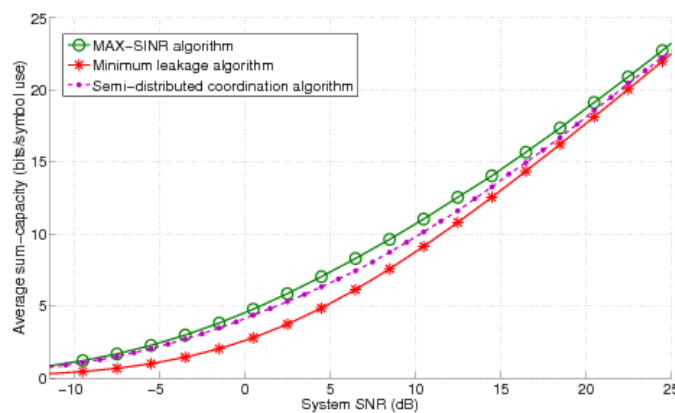


Figure 9.25: Average sum-capacity of the proposed coordination algorithms compared to the minimum leakage and the MAX-SINR algorithms when using 1dB target SNR granularity for the 3-user 2×2 MIMO IC with $d_k = 1, \forall k = 1, 2, 3$

Figure 9.25 illustrates the average sum-capacity evolution of the proposed algorithms compared to the minimum leakage and MAX-SINR algorithms [YTJ+08]. The figure shows that the proposed algorithms outperform the minimum leakage algorithm in low and medium SNR regions and approaches the performance of the MAX-SINR algorithm. The same figure

shows that at high system SNR, the minimum leakage and MAX-SINR algorithms outperform the semi-distributed algorithm in terms of sum-capacity. Such behavior can be overcome if we use higher target SINRs as design parameter which will push it to imitate the minimum leakage algorithm behavior in these system SNR regions.

Figure 9.26 illustrates the number of required iterations for convergence for the proposed semi-distributed coordination algorithm and the minimum leakage algorithm. The evolution is drawn function of the system SNR. The figure shows that the proposed algorithms require less iterations to converge compared to the minimum leakage algorithm. From another side, from the figure we notice that the proposed algorithm is the most advantageous in terms of implementation complexity seeing that it requires the least number of iterations to converge. Recall that no comparison is made with the MAX-SINR algorithm in terms of convergence speed seeing that its convergence is not always guaranteed.

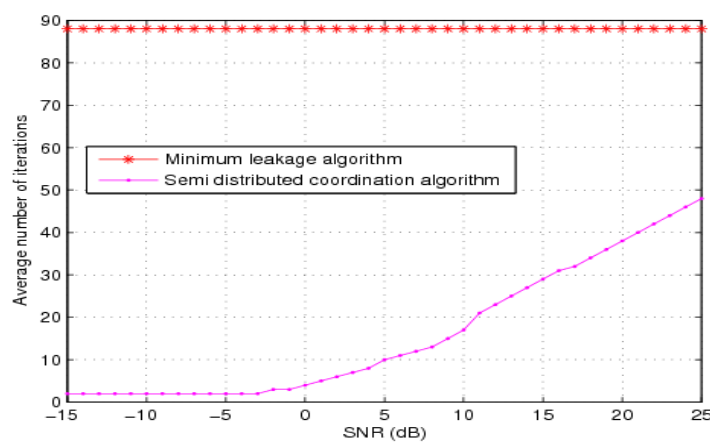


Figure 9.26: Average Number of iterations for the proposed coordination algorithms compared to the minimum leakage algorithm for the 3-user 2x2 MIMO IC with $d_k = 1, \forall k = 1, 2, 3$

9.2.6.1 Acronyms

AP	Access Point
CU	Central Unit
MIMO IC	MIMO interference channel
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio

9.2.6.2 References

- [HJF+10] A. Hafeez, G. Jiann-Ching, A. Furuskar, and P. Skillermark, "Multi-cell beamforming under per-cell power constraints," in Proc. IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), 2010, Ottawa, ON, pp. 1–5, Sep. 2010.
- [HS12] S. B. Halima and A. Saadani "An adaptive cooperation algorithm based on trade off between useful signal and interference alignment," in IEEE International Symposium on personal, Indoor and Mobile Radio Communications (PIMRC2012), Sydney, Australia, Sep. 2012.
- [KF10] K. Kumar and X. Feng, "An iterative algorithm for joint signal and interference alignment," in Proc. IEEE International Symposium on Information Theory Proceedings (ISIT), 2010, Austin, TX, pp. 2293–2297, Jun. 2010.
- [LLX+09] A. Liu, Y. Liu, H. Xiang, and W. Luo, "On the rate duality of MIMO interference channel and its application to sum rate maximization," in Proc. IEEE Global Telecommunications Conference, 2009. GLOBECOM 2009, Honolulu, HI, Dec. 2009.



Document: FP7-ICT-317669-METIS/D3.2

Date: 23/04/2014

Security: Public

Status: Final

Version: 1

[YTJ+08] C. Yetis, G. Tiangao, S. Jafar, and A. Kayran, "Approaching the capacity of wireless networks through distributed interference alignment," in Proc. IEEE Global Telecommunications Conference, 2008. GLOBECOM 2008, New Orleans, LO, Dec. 2008.

9.2.7 T3.2 TeC.06 Distributed low-overhead schemes for MIMO Interference Channels

The main focus of the proposed TeC is to greatly enhance the spectral efficiency of DL and UL transmission in dense HetNet scenarios – which constitute the core of the network densification paradigm. The proposed schemes advocate the use of training via UL / DL pilots in a TDD network - also known as forward-backward (F-B) or “ping pong” iterations, to iteratively optimize the transmit / receive filters, in a fully distributed manner (Figure 9.27a). This training phase precedes the actual data transmission phase. Although this concept has been used earlier on, our main contribution is to modify the structure of the aforementioned F-B iteration – by introducing a so-called turbo iteration, to reduce the required number of such iterations, from hundreds, to just a few. We propose two different schemes based on the above general structure (that we dub Iterative Weight Updates, IWU), based on the requirement that filters be full-rank (IWU-RP) or rank-deficient (IWU-RR). Finally, we underline the fact that the proposed schemes are to be combined with clustering and user selection algorithms to serve a given dense network of users.

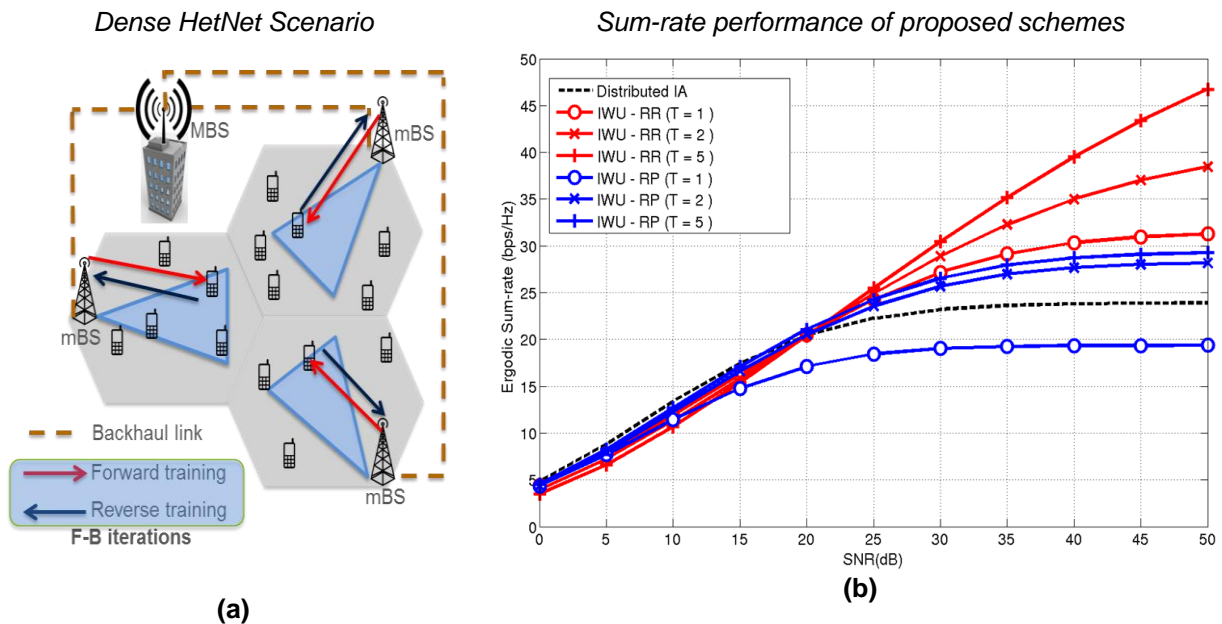


Figure 9.27: System model and main result

We evaluate the average sum-spectral efficiency of both schemes for a 3-user, 4x4 MIMO interference channel (with 2 streams/user), in a Rayleigh fading environment, and compare it to the well-known Distributed Interference Alignment algorithm [GCJ08]. We fix the number of F-B iterations to 2, and evaluate the performance of the proposed schemes for different number of turbo-iterations, T . As we can see from Figure 9.27b, both schemes significantly outperform the benchmark, especially in the medium-to-high SNR regime. Furthermore, we see that the rank-reducing scheme, IWU-RR, offers the highest performance. This is due to the fact that reducing the filter rank reduces the effective dimension of the interference – a vital condition to increasing the spectral efficiency in high interference conditions.

In addition, feedback overhead (in FFD) being the main challenge of dense setting such as the one considered by this TeC, we see that the distributed nature of the proposed schemes (only local CSI is needed), combined with the use of channel reciprocity in TDD operation, fully mitigates the problem. Those results seem to support the premise that a distributed TDD architecture seems to be better positioned to deliver the high spectral efficiency required for 5G communication.



9.2.7.1 Acronyms

DL / UL	Downlink / Uplink
HetNet	Heterogeneous Network
IWU RP	Iterative Weight Updates Rank Preserving
IWU RR	Iterative Weight Updates Rank Reducing
TDD	Time-Division Duplexing
FDD	Frequency-Division Duplexing
F-B	Forward-Backward

9.2.7.2 References

[GKB+14] H. Ghauch, T. Kim, M. Bengtsson, M. Skoglund, "Distributed Low-Overhead Schemes for Multi-stream MIMO Interference Channels," manuscript in preparation, to be submitted to IEEE Trans. on Signal Processing.

[GCJ08] K. S. Gomadam, V. R. Cadambe and S. A. Jafar, "Approaching the Capacity of Wireless Networks through Distributed Interference Alignment," Proceedings of IEEE GLOBECOM, New Orleans, LA, Dec. 2008.

9.2.8 T3.2 TeC.07 Dynamic clustering with multiple receive antennas in downlink CoMP systems

We consider a hexagonal cellular scenario where 21 base stations (BSs), each equipped with 4 antennas, are grouped in 7 sites, each one with 3 co-located BSs, with an inter-site distance of 500 m. We consider 210 user equipments (UEs), with 10 UEs randomly dropped in the coverage area of each BS. The channel model includes path-loss, shadowing, directive antennas at the BSs and fast fading. Moreover, we implement proportional fair scheduling to provide fairness among the UEs. In Figure 9.28 we report the 5th percentile of the UE rate with respect to the number N of UE antennas, by assuming rank-1 transmission and interference rejection combiner (IRC) at the UE. We compare the developed scheme based on dynamic clustering (DC) by assuming an average cluster size of 3 BSs against: a) single cell processing (SCP), where each UE is served by its anchor BS and no cooperation is allowed among the BSs in the network, and b) static clustering (SC), where 7 clusters, each composed by the 3 BSs of the same site, are constructed to serve the UEs, without any adaptation of the clusters to the channel conditions.

By adding antennas at the UE, we observe an important performance improvement as IRC is able to strongly limit the inter-cluster interference at the detection point. For instance, with SCP by increasing N from 1 to 4 there is an improvement of about 80%. Then, we also observe that the performance gain of DC over SCP decreases by increasing N : this gain decreases from about 50% with $N=1$ to about 15% with $N=4$. In fact, as the inter-cluster interference not managed at the transmit side is higher for SCP than DC, IRC provides more benefits to the non-cooperative baseline scheme.

More details and results considering also multi-stream transmission, antenna correlation and different cluster sizes can be found in [BBB13a] and [BBB13b].

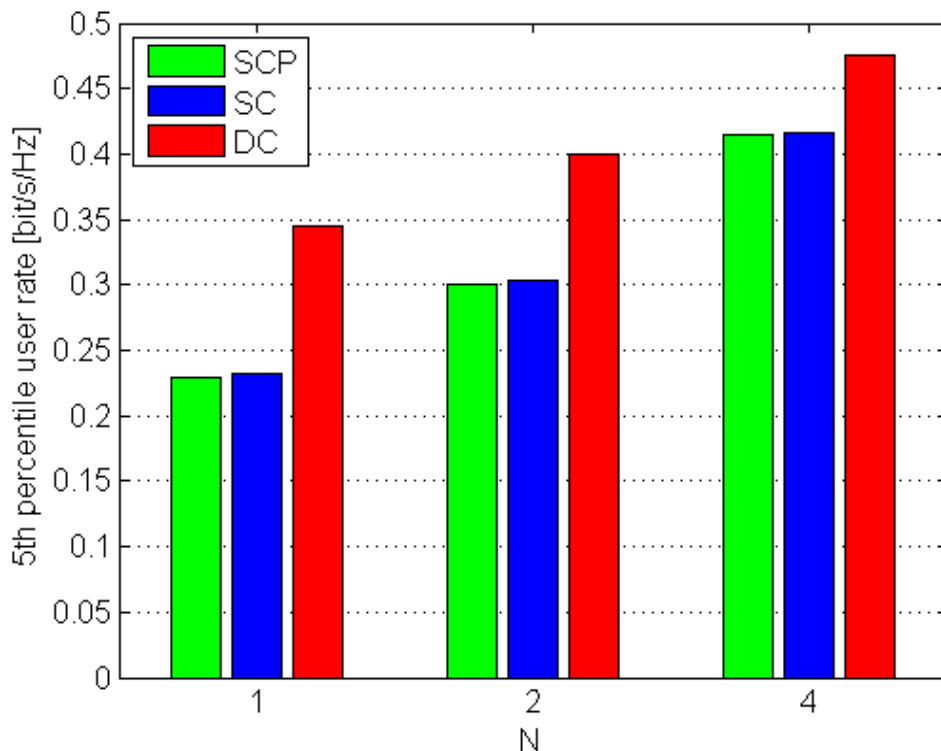


Figure 9.28: 5th percentile of the UE rate with respect to the number of UE antennas



9.2.8.1 Acronyms

BS	Base Station
CoMP	Coordinated Multi-Point
DC	Dynamic Clustering
IRC	Interference Rejection Combiner
SC	Static Clustering
SCP	Single Cell Processing
UE	User Equipment

9.2.8.2 References

[BBB13a] P. Baracca, F. Boccardi, and N. Benvenuto, "Clustering with multiple receiving antennas in downlink FDD CoMP systems," in Proc. IEEE International Conference on Signal Processing, Computing and Control (ISPCC), Shimla (India), Sep. 2013.

[BBB13b] P. Baracca, F. Boccardi, and N. Benvenuto, "A dynamic clustering and resource allocation algorithm for downlink CoMP systems with multiple antenna UEs," available at <http://arxiv.org/abs/1311.5114>, Nov. 2013.

9.2.9 T3.2 TeC.08 Non Orthogonal Multiple Access

We proposed a downlink non-orthogonal multiple access (NOMA) scheme where multiple users are multiplexed in the power-domain on the transmitter side and multi-user signal separation on the receiver side is conducted based on successive interference cancellation (SIC) [HK12] [EKH12] [UKH12] [OKH12].

In this study, we evaluate the system-level performance gains of NOMA over OMA, assuming adaptive modulation and coding (AMC), frequency-domain scheduling, outer loop link adaptation (OLLA), in addition to NOMA specific functionalities such as multi-user power allocation. It is shown that the overall cell throughput, cell edge user throughput and the degree of proportional fairness achieved by NOMA are all superior to that of OMA [SBKN13].

We assume K users per cell and the total transmit bandwidth, BW , is divided into S subbands, where the bandwidth of each subband is B . We assume that the multi-user scheduler selects m_s users from K then schedules a set of users, $U_s = \{i_s(1), i_s(2), \dots, i_s(m_s)\}$, to subband s ($1 \leq s \leq S$), where $i_s(l)$ indicates the index of the l -th ($1 \leq l \leq m_s$) user scheduled at subband s , and m_s denotes the number of users non-orthogonally multiplexed at subband s . For NOMA with SIC, we assume that the receiver of user $i_s(l)$, is able to cancel perfectly and successively the interference from other user(s) j with channel gain $G_s(j)/N_s(j)$ lower than $G_s(i_s(l))/N_s(i_s(l))$. This assumption is reasonable because users with lower channel gains, as explained later, are allocated higher levels of transmit power than users with higher channel gains. Note that the decoding and the successive cancellation order of signals from other users with higher channel gains are carried out in the order of the increasing channel gain. On the other hand, at the receiver of each user, $i_s(l)$, the received signal from other user(s) j with channel gain $G_s(j)/N_s(j)$ higher than $G_s(i_s(l))/N_s(i_s(l))$ is treated as noise.

In NOMA, the power allocation to one user affects the achievable throughput of not only that user but also the throughput of other users due to power-domain multi-user multiplexing. Therefore, multi-user transmit power allocation and multi-user scheduling are connected to each other. For the sake of simplicity, in this study we assume disjoint power allocation and user scheduling where the power allocation for each candidate user set, U_s , is conducted first and then the scheduling metric is calculated. For each subband the scheduler allocates more than one user for simultaneous transmission. Proportional fairness (PF) scheduler is known to achieve a good balance between system capacity and user fairness. In [KG05], the multiuser scheduling version of the PF scheduler here used is presented and an approximated version is derived.

First, the performance gain of NOMA over OMA is investigated for $S = 1$, i.e., wideband scheduling for OMA and wideband user multiplexing for NOMA. Figure 9.29 provides the CDF of the user throughput for OMA ($m=1$) and NOMA with the maximum multiplexing order of $m = 2$ and $m = 3$ for the number of UEs per cell of $K = 10$. The performance gains in the overall cell throughput and cell-edge user throughput for NOMA over OMA for $m = 2$ ($m = 3$) are approximately 27% (28%) and 34% (39%), respectively. Note that the most of NOMA gains are obtained with $m = 2$.

Next, we investigate the throughput performance of NOMA with different numbers of subbands: $S = 1, 2, 4$, and 8 . NOMA gains for different numbers of subbands are summarized in Table 9.3. The gains of NOMA in terms of overall cell throughput, cell-edge throughput, and degree of proportional fairness (geometric mean throughput) are reduced compared to those for OMA as the number of subbands is increased. This is due to two reasons: OMA has higher frequency-domain scheduling with more subbands, and NOMA achieves lower multiplexing gains since the user transmit power allocation is per subband while the MCS selection remains wideband. Thus, with larger number of subbands, subband MCS selection is required to achieve larger gains for subband NOMA.

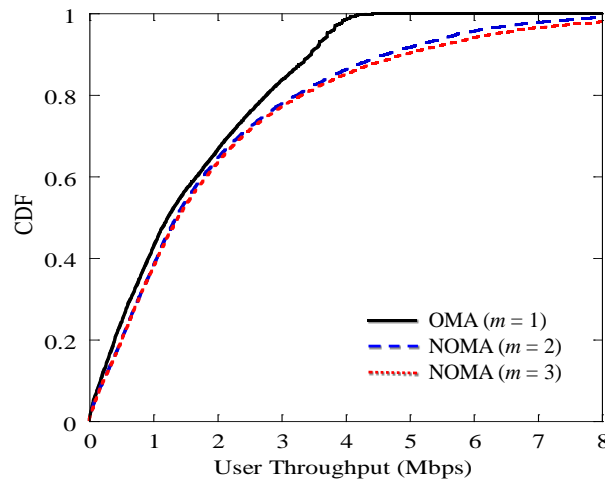


Figure 9.29: CDF of user throughput for OMA ($m = 1$) and NOMA ($m = 2, 3$) with $S = 1$ and $K = 10$.

Table 9.3: Performance gain for different numbers of subbands

Number of subbands (S)	Cell throughput gain [%]	Cell edge throughput gain [%]	Geometric mean throughput gain [%]
1	27	28	22
2	26	28	20
4	23	22	17
8	19	15	13

Finally, we investigate the performance of NOMA with outer loop link adaptation and error propagation at the UE close to the BS, where SIC is applied. For the sake of simplicity, we emulate error propagation by assuming the worst-case performance, where the decoding of the desired (second decoded) user is always unsuccessful if the decoding of the first decoded (non-desired) user fails. Figure 9.30 shows the CDF of user throughput for NOMA with $S = 1$, $m = 2$, and $K = 10$, including OLLA and error propagation. As a comparison, the performance of OMA ($m = 1$) with and without OLLA is also plotted. Figure 9.30 shows that the effect of the error propagation is negligibly small for both the performance of NOMA with and without OLLA although worst-case performance was assumed for error propagation. The performance gains in the overall cell throughput and cell-edge user throughput for NOMA with OLLA over OMA with OLLA are approximately 24% and 26%, respectively.

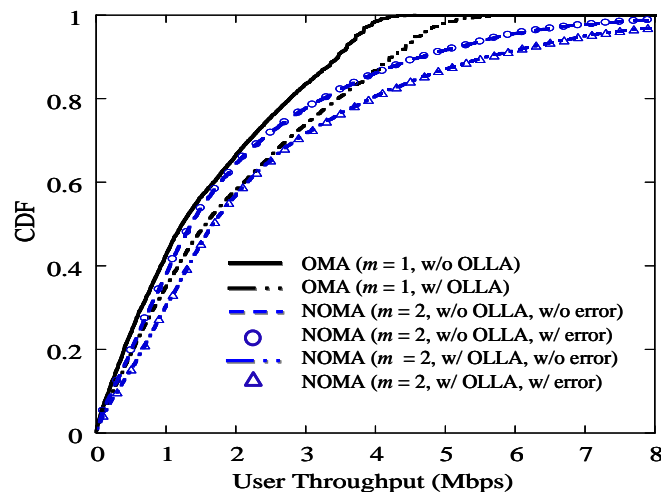


Figure 9.30: CDF of user throughput including OLLA and error propagation for SIC in NOMA ($m = 2$), with $S = 1$ and $K = 10$.



The above study provides initial evaluations of NOMA gains in terms of intra-cell user multiplexing for the 1x2 SISO case with no inter-cell interference mitigation. In the next step, we plan to extend our evaluations to MIMO case. In addition, inter-cell interference also plays a limiting factor under multi-cell environments. It is therefore important to also study how to combine NOMA with inter-cell interference mitigation techniques in order to further boost spectrum efficiency, system throughput and cell-edge user throughput. Inter-cell interference mitigation techniques can be generally categorized to centralized and distributed schemes. How to combine both categories of techniques with NOMA is of interest to our future work.

9.2.9.1 Acronyms

AMC	Adaptive Modulation and Coding
CDF	Cumulative Distribution Function
MCS	Modulation and Coding Scheme
NOMA	Non-Orthogonal Multiple Access
OLLA	Outer Loop Link Adaptation
OMA	Orthogonal Multiple Access
PF	Proportional Fairness
SIC	Successive Interference Cancellation

9.2.9.2 References

- [HK12] K. Higuchi and Y. Kishiyama, "Non-orthogonal access with random beamforming and intra-beam SIC for cellular MIMO downlink," IEICE RCS2012-89, vol. pp. 85-90, July 2012.
- [EKH12] Y. Endo, Y. Kishiyama, and K. Higuchi, "A study on transmission power control considering inter-cell interference for non-orthogonal access with MMSE-SIC in cellular uplink," IEICE RCS2012-46, pp. 19-24, June 2012.
- [UKH12] J. Umehara, Y. Kishiyama, and K. Higuchi, "Enhancing user fairness in non-orthogonal access with successive interference cancellation for cellular downlink," Proc. of ICCS, Nov. 2012.
- [OKH12]. N. Otao, Y. Kishiyama, and K. Higuchi, "Performance of non-orthogonal access with SIC in cellular downlink using proportional fair-based resource allocation," ISWCS, pp. 476-480, Aug. 2012.
- [KG05] M. Kountouris and D. Gesbert, "Memory-based opportunistic multi-user beamforming," Proc. IEEE Int. Symp. Information Theory (ISIT), Adelaide, Australia, Sept. 2005.
- [SBKN13] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "System-level performance evaluation of downlink non-orthogonal multiple access (NOMA)," IEEE PIMRC 2013, Sept. 2013.

9.2.10 T3.2 TeC.10 Distributed Joint-Transmission CoMP with enhanced multi-antenna receive processing

This work focuses on the LTE-A FDD downlink CoMP-JT. We introduce CSI for the purpose of dynamic clustered CoMP-JT. User grouping is based on a greedy, semi-orthogonal user scheduling method. Based on CSI from the selected set of users, we derive the ZF precoder and the corresponding power allocation. Finally, we compare achievable system and user performance by using extensive multi-cell simulations following latest 3GPP guidelines. For comparison we use limited feedback transmission concept from [TKOH13] utilizing PMI feedback from the users for the selection of single-cell precoding, while CQIs are used for appropriate user grouping and adaptive modulation and coding.

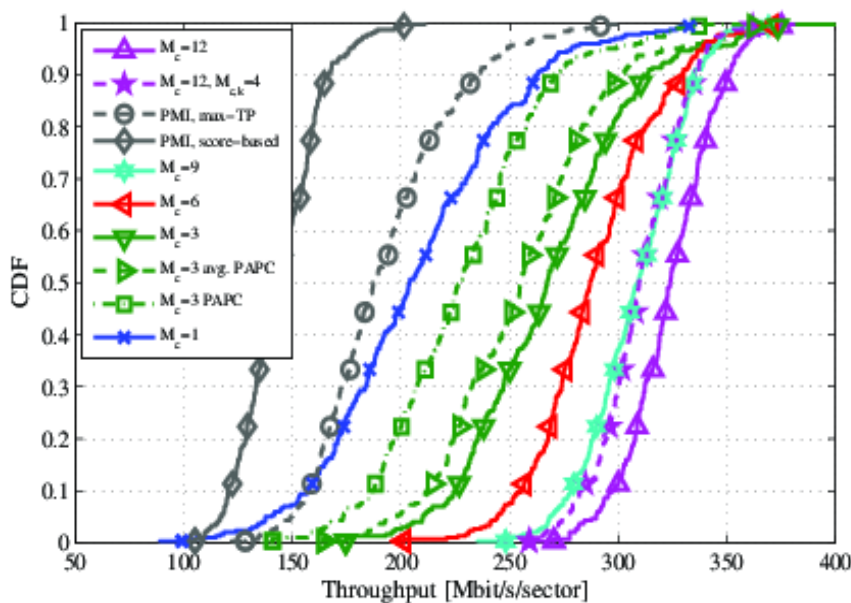
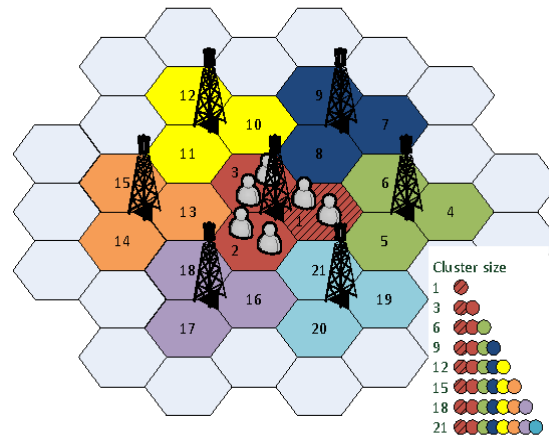


Figure 9.31: Different transmission strategies ranging from limited feedback assumptions, i.e. PMI based precoding (under sum-rate maximization as well as fair resource allocation) and clustered ZF precoding. If not stated differently transmit power is always distributed under a per-base-station power constraint.

Based on system-level simulations, the right hand side of Figure 9.31 shows the achievable sum-rate per sector obtained with 20 MHz bandwidth. The baseline labelled with PMI is carried out under a sum-rate maximization as well as under an equal amount of resources (score-based) resource scheduling approach. The sum-rate is dropping by approx. 24% due to a fair resource allocation. As a next step we include the performance for a ZF precoding



assumption per sector $M_c = 1$, i.e. each sector is independently performing the precoding and resource allocation without considering the effect of cross-sector interference. Note that we ensure a certain degree of fairness by distributing the first spatial layer per time and frequency resource under a score-based criterion. Therefore, we assume that the users are generating CQI feedback by considering the out-of-cell/cluster interference only. By utilizing this specific type of CQI feedback, each user is mainly scheduled on those resource elements, where he perceives best SINR conditions with respect to dominant and non-coordinated interference.

Finally we increase the region for joint ZF precoding by adding multiple sectors into the so-called CoMP cluster. The clustering methodology is depicted in the upper side in Figure 9.31. Especially for multi-sector joint precoding transmit power constraints play an important role. Once we distribute the transmit power budget under a strict PAPC, each resource element is independently treated from each other and thus the theoretical overall power budget is utilized with 54% only. For the average PAPC, each transmit antenna needs to meet the power budget averaged over frequency domain. This relaxes the power normalization significantly. The next step is a per-BS power constraint where each cluster can transmit with up to 96% of the available total power. Note that once we increase the cluster-size we need to exchange both payload and CSI of all active users. Therefore, we include a reference CDF which corresponds to the case where each user is allowed to report a maximum of 4 cell-ids $M_c = 12$, $M_{c,k} = 4$ at rather small loss in system's sum throughput. The robustness in terms of channel feedback outdated as well as potential gains from linear channel prediction is also currently under study.

9.2.10.1 Acronyms

CoMP	Coordinated Multi-Point
CoMP-JT	CoMP joint transmission
CDF	Cumulative Distribution Function
CQI	Channel Quality Indicator
CSI	Channel State Information
CSIT	CSI at the Transmitter
OFDM	Orthogonal Frequency Division Multiplex
PAPC	Per Antenna Power Constraint
PMI	Precoding Matrix Indicator
SINR	Signal-to-Interference-and-Noise Ratio
ZF	Zero-Forcing

9.2.10.2 References

[METISD31] METIS consortium, "D3.1 – Positioning of multi-node/multi-antenna technologies," project report, July 2013

[TKOH13] L. Thiele, M. Kurras, M. Olbrich and T. Haustein, "Boosting 4G Networks with Spatial Interference Management Under Feedback Constraints: A Noncooperative Downlink Transmission Scheme," Vehicular Technology Magazine, IEEE, vol. 8, pp. 40-48, Mar 2013

9.2.11 T3.2 TeC.11 Decentralized interference aware scheduling

In the proposed scheme, the scheduler computes scheduling metrics $\mu_{n,k}$ for each user n that it serves on each radio resource k where the transmission can be mapped. Then, the user and resource pair with the maximum metric is allocated for transmission. As the scheduling metric may depend on the estimated average throughput for the user (as in the PF scheduler and also in DIAS), the metrics have to be recalculated after each allocation. This process is repeated until all resources have been considered for transmission. In order to define the PF and DIAS scheduling metrics, let us define the following quantities: $T_{n,k}^+$, throughput of UE n if active on resource k ; $T_{n,k}^-$, throughput of n if not active on k ; $Q_{mn,k}^+$, throughput of m -th victim if n is active on k ; $Q_{mn,k}^-$, throughput of m -th victim if n is not active on k . With these definitions, the non-interference aware PF scheduling metric is

$$\mu_{n,k}^{\text{PF}} = \log T_{n,k}^+$$

For DIAS, we use the following metric:

$$\mu_{n,k}^{\text{DIAS}} = \frac{1}{V+1} \left(\log T_{n,k}^+ - \log T_{n,k}^- + \sum_{m=1}^V Q_{mn,k}^+ - \sum_{m=1}^V Q_{mn,k}^- \right),$$

where V is the number of interference victims (received beacons). The DIAS scheduling metric weighs the benefit of desired link against the degradation of interfered links in the scheduling decision. The transmission decision is only made if the scheduling metric is positive, that is if the system utility can be improved upon. Otherwise, a resource may be left un-used if the interference that is generated results in more throughput loss at the victims, than what would be gained for the desired receiver.

The scheme relies on certain continuity of the scheduling decisions. When calculating the scheduling metrics it is assumed that the other transmitters keep the same scheduling decisions; otherwise the throughput prediction involved in the scheduling metric computation could not be done. This is achieved by randomizing the scheduling updates. In this approach, each scheduler/transmitter updates its resource allocation only with probability $p < 1$. This operation guarantees that the transmission schedules converge to a (local) optimum with probability 1, see [JRK11].

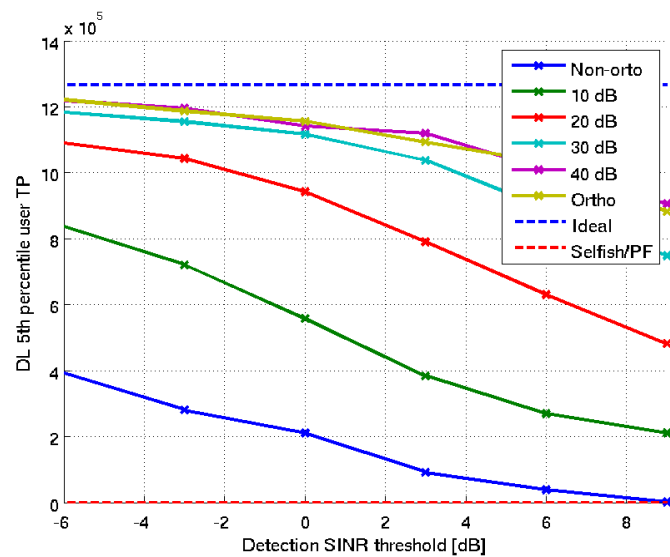


Figure 9.32: Downlink cell edge user throughput assuming different beacon detection SINR threshold and beacon orthogonality. Ideal DIAS and PF scheduler performance are shown for comparison with dashed line.

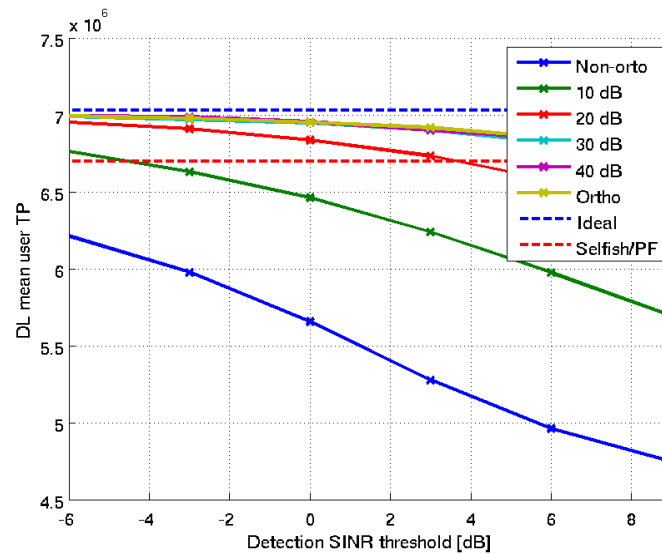


Figure 9.33: Downlink mean user throughput assuming different beacon detection SINR threshold and beacon orthogonality. Ideal DIAS and PF scheduler performance are shown for comparison with dashed line.

Simulations were conducted to compare the DIAS and PF scheduling schemes in the scenario outlined in section 3.4.2. In order to assess the sensitivity of DIAS to the reliability of the beacon message reception, each data resource is assumed to be accompanied with 8 beacon resources that are multiplexed e.g. in frequency domain. Each receiver is assigned one of the 8 beacon resources randomly. The transmitters are assumed to be listening to all of the beacons resources, and a beacon is assumed to be received correctly if its SINR exceeds a threshold value. A range of -6dB to 9 dB SINR threshold was simulated. The 8 beacon resources are further assumed to be quasi-orthogonal, such that a beacon transmission on one resource leaks interference to all other beacon resources, and the leakage ratio is varied between 10 dB and 40 dB.

Figure 9.32 and Figure 9.33 show the performance as the cell edge user throughput (5th percentile of the throughput CDF) and mean user throughput. Due to the Closed Subscriber Groups assumption, PF scheduler is not able to provide any cell edge throughput, as observed from Figure 9.32. Applying DIAS remedies the situation, and a reasonable performance is obtained at 30 dB orthogonality and 0 dB SINR threshold. With this level of beacon reliability, the mean user throughput is improved compared to the PF scheduler by about 5%, see Figure 9.33. As a conclusion, DIAS is able to salvage the cell edge throughput, and at the same time also improve the mean throughput. Note that the 10% increased overhead for DIAS is taken into account in the simulations. This means that the peak throughput with DIAS is only 90% of the PF scheduler peak throughput.

9.2.11.1 Acronyms

CSG	Closed Subscriber Groups
DIAS	Decentralized Interference Aware Scheduling
PF	Proportional Fair

9.2.11.2 References

[JRK11] P. Jänis, C. Ribeiro, V. Koivunen, "Interference Aware Radio Resource Management for Local Area Wireless Networks," EURASIP Journal on Wireless Communication and Networking, vol. 2011, article ID 921623, pp. 1–15, 2011.

9.2.12 T3.2 TeC.12 Network-assisted interference suppressing/cancelling receivers and ultra-dense networks

In case of network-assisted (NA) interference cancellation/suppression (IC/IS) [3GPP13-RP130404], enhancement in UE receivers' ability to cope with inter-cell interference is targeted by exploiting assistance from network side. Such assistance can comprise signalling of aggressor (interferer) signal parameters to a victim UE and/or coordination of transmission parameters among neighbouring cells in attempt to improve inter-cell interference estimation accuracy and consequent mitigation performance of a victim UE receiver.

With the aid of network assistance, advanced interference suppressing (linear) and cancelling (non-linear) UE receivers can be constructed that perform explicit channel estimation of interfering link(s), enabling more accurate interference covariance estimation. As a result, these receivers can potentially obtain improved post-processing SINRs, compared to those of non-NA IC/IS receivers [3GPP12-36829][PIB+13], providing means for higher experienced user throughputs in inter-cell interference limited scenarios.

Figure 9.34 depicts the potential gain from network assistance, measured as the SINR gain over the Rel-11 linear IRC baseline receiver [3GPP12-36829] at 70% maximum throughput level of PDSCH (dotted red line in the figure). PDSCH throughput vs. geometry results are shown for genie-aided NA E-LMMSE-IRC and SLIC receivers (i.e., with full knowledge of relevant interferer signal parameters at a victim UE), in addition to LMMSE-IRC baseline. Also performance AWGN-optimized LMMSE receiver is shown for reference. The performance assessment was carried out assuming a scenario of two interfering cells with an interference profile of INR = [7.77 2.29] (dB) and TM9 rank-1 transmissions with serving cell MCS#5 and interfering cells' MCS#5 in EPA-5Hz channel. Moreover, a 50 PRB PDSCH allocation, a 2x2 antenna configuration and practical channel and covariance estimators are assumed.

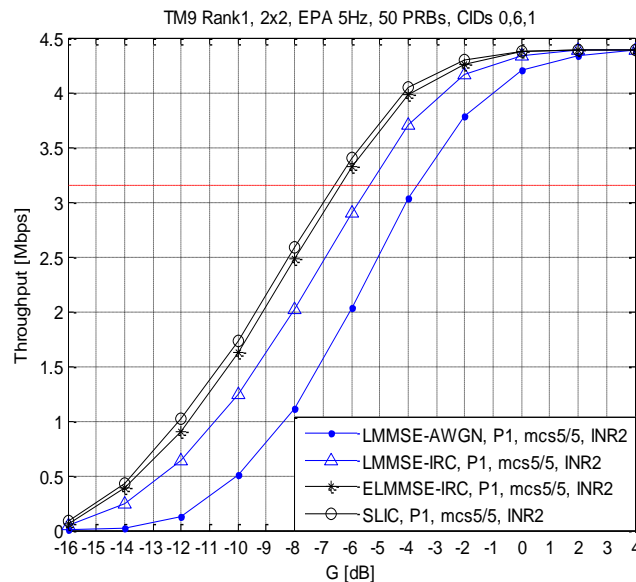


Figure 9.34: Throughput vs. geometry (SINR) performance of advanced NA E-LMMSE-IRC and SLIC receivers, in comparison to the Rel-11 baseline (LMMSE-IRC).

According to Figure 9.34, network assistance has potential to further improve the inter-cell interference robustness of advanced interference cancelling/suppressing receivers (beyond that of the non-NA baseline), providing means for increased cell spectral efficiency at the cost of associated signalling of required NA information and increased processing complexity of a victim UE receiver.



9.2.12.1 Acronyms

AWGN	Additive White Gaussian Noise
NA	Network-Assisted
IC	Interference Cancellation
IRC	Interference Rejection Combining
E-LMMSE	Enhanced LMMSE
EPA	Extended Pedestrian A
LMMSE	Linear Minimum Mean Square Error
MCS	Modulation and Coding Scheme
INR	Interference-to-Noise Ratio
IS	Interference Suppression
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
SINR	Signal-to-Interference-plus-Noise Ratio
SLIC	Symbol-Level IC
UE	User Equipment

9.2.12.2 References

[3GPP13-RP130404] RP-130404, "Study on network-assisted interference cancellation and suppression for LTE," MediaTek, Renesas Mobile Europe, Broadcom Corporation, Vienna, Austria, Feb. 2013.

[3GPP12-36829] TR 36.829, "Enhanced performance requirements for LTE user equipment (UE)," Release 11, v11.1.0 (2012-12).

[PIB+13] P. Papadimitriou, T. Ihalainen, H. Berg and K. Hugi, "Link-level performance of an LTE UE receiver in synchronous and asynchronous networks," WCNC2013, Shanghai, China, April 2013.

9.2.13 T3.2 TeC.13 Extension of IMF-A interference mitigation framework to small cell scenarios and Massive-MIMO

Interference mitigation, massive MIMO and small cells are expected to be main drivers to an increased spectral efficiency in future mobile radio networks. Based on joint transmission cooperative multipoint (JT CoMP) the so called Interference Mitigation Framework (IMF-A) has been developed in the FP7 project Artist4G [ARTIST14] and laid the foundation to notable performance gains with respect to coverage and average spectral efficiency. Still to be investigated is the best way to integrate massive MIMO and small cells into this IMF-A framework.

In the meantime, first analysis and simulations have been performed for a better understanding of the benefits of massive or more importantly of large scale MIMO in the context of future 5G wide area concepts. So far the main focus is on ray tracing results in the Munich NSN campus area as depicted below. A 16 x 8 massive MIMO array has been placed in the upper right angle at a height of 35m. All vertical antenna elements are standard Kathrein antennas as typically being used in today's wide area networks consisting of a row of 8 antenna elements. Beamforming is limited in this case to the horizontal plane by according precoding of the 16 antennas. As can be concluded from the right figure below there is still a lot of inter-wideband interference (color coded in dB values) at UE side (x-axis) for the 16 wideband beams (y-axis).

At least for lower RF-frequencies of around 2 to 3GHz and reasonable number of antenna elements in real world scenarios there will be still a strong inter-beam interference. A powerful interference mitigation technique should be therefore of great benefit, especially in multi-cell scenarios.

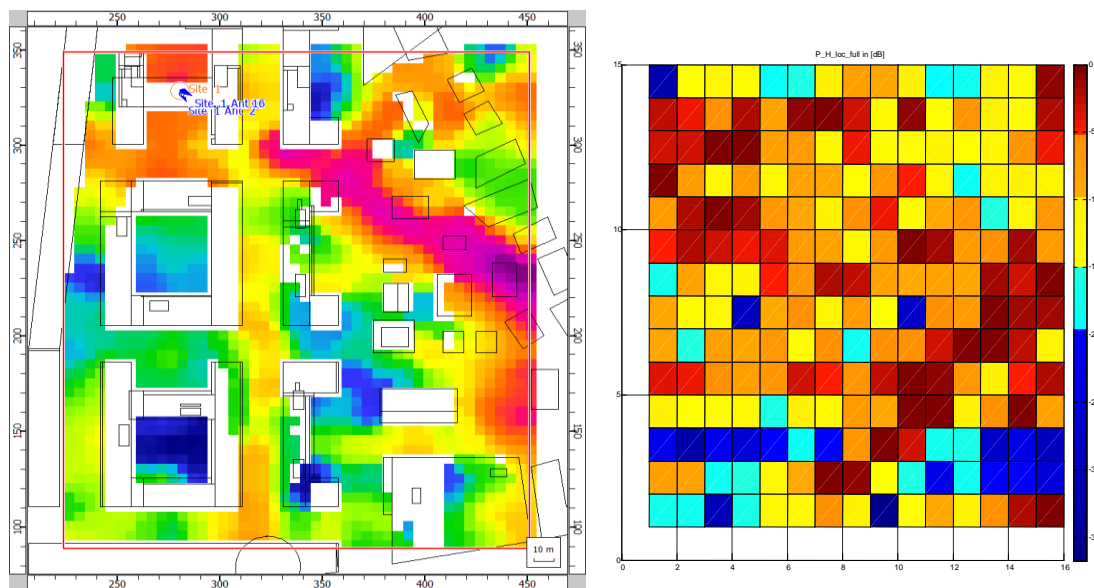


Figure 9.35: left: single cell raytracing simulation for massive MIMO array with 5 degree beam width; right: colour coded relative receive power of 16 x 8 array forming 16 wideband beams for 15 randomly placed UEs inside the NSN campus

9.2.13.1 Acronyms

CoMP	Coordinate Multi Point
IMF-A	Interference Mitigation Framework from Artist4G
JT	Joint Transmission



9.2.13.2 References

[ARTIST14] ARTIST4G consortium, "D1.4 – Interference Avoidance techniques and system design," project report, July, 2012

[GHZ+12] N. Gresset, H. Halbauer, W. Zirwas, H. Khanfir, "Interference Avoidance Techniques for Improving Ubiquitous User Experience," IEEE VTM magazine, Dec 2012

[FKV06] G. Foschini, K. Karakayali, and R. Valenzuela, "Coordinating multiple antenna cellular networks to achieve enormous spectral efficiency," IEEE Proceedings-Communications, vol. 153, pp. 548-555, Aug. 2006



9.2.14 T3.2 TeC.14 Joint dynamic clustering and coordinated scheduling for relaying with Physical Layer Network Coding

At this stage of the project work on this TeC has been more informative on the considered scenario and simulation setup, since the proposed innovation is based on the concept currently under study in Task 3.3 TeC 10. A detailed description of the work carried out in Task 3.3, together with preliminary simulation results, is available in section 9.3.10.

9.2.15 T3.2 TeC.15 Adaptive and energy efficient dense small cells coordination

In this TeC we focused on the design of a CoMP based scheduling algorithm that allows to reduce power consumption in a dense network when traffic is below the peak.

In a non-coordinated system always the best BS is used to schedule one UE. However, if in a dense deployment there are other BSs that can be used to serve the user it is possible to reduce the number of active BSs when traffic is not too high. With this aim we defined a scheduling algorithm that follows a greedy approach and tries to reduce the number of active BSs, recursively allocating frequency resources and balancing Joint Transmission (JT) and Dynamic Points Selection with Blanking (DPS/B), while still satisfying user requests.

The scheduler is centralized and manages all BSs in the scenario. It receives as inputs the size of transmission buffers for the UEs and a map with the CSI for the 3 best BSs of each UE.

For this preliminary evaluation, we considered a simplified version of T3.2 baseline, with SISO transmission, omni Micro BSs and large scale fading following PS1 and PS3 models defined in [METIS61]. A small scale fading effect is included as a time-correlated Rayleigh variable (velocity = 3kmh). The system bandwidth is 10 MHz and Macro and Micro BS power consumption models follow the recommendation in [EARTH23] (including sleep mode).

Traffic source is either fullbuffer or Constant Bit Rate, with fixed size packets generated every randomly generated time interval, so that the average source rate is equal to a given value.

As shown in Figure 9.36, compared with a non coordinated solution we achieve lower system rate in a full buffer scenario, but still we can satisfy high level of throughput demand when non-full buffer traffic is considered. Moreover, in low/medium load we can save up to 27% power compared to a non-coordinated approach. Savings are achieved thanks to the lower resource usage achieved by exploiting Joint Transmission with Dynamic Blanking.

It should be noted that Test Case 2 Task 3.2 baseline do not look as the most promising environment to test the solution. We expect higher savings in a scenario with a higher number of overlapping cells, e.g. the Stadium test case.

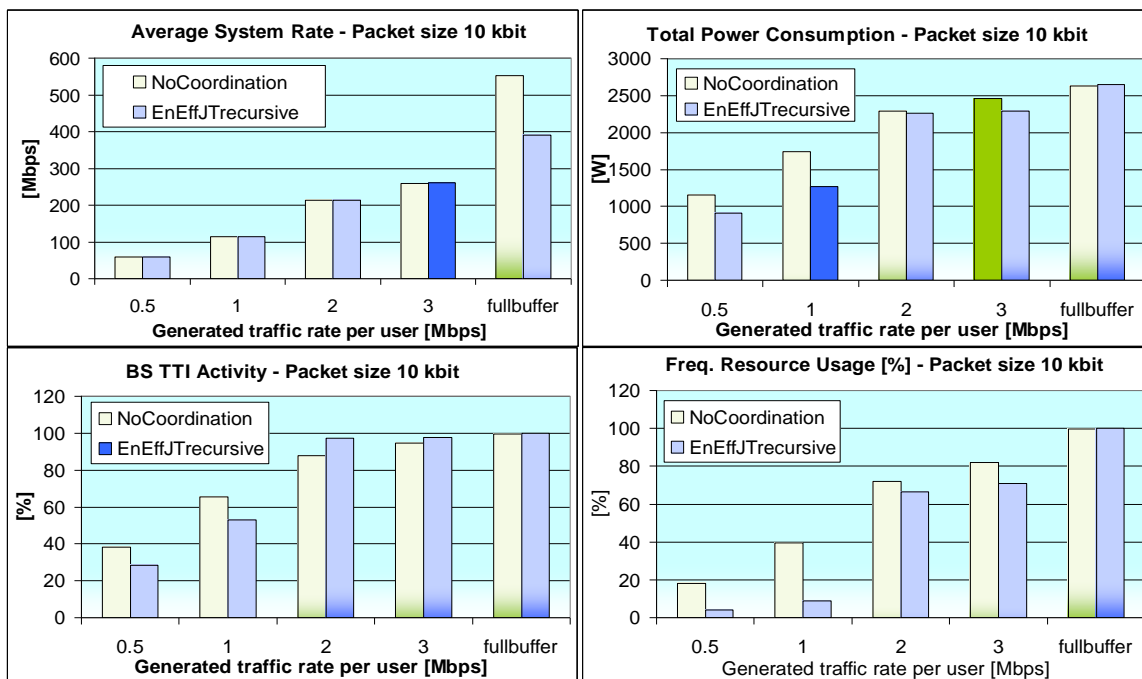


Figure 9.36: Task 3.2 TeC 15 simulation results



9.2.15.1 Acronyms

BS	Base Station
CSI	Channel State Information
DPS/B	Dynamic Points Selection with Blanking
JT	Joint Transmission
SISO	Single Input Single Output
UE	User Equipment

9.2.15.2 References

[METIS61] METIS consortium, "D6.1 – Simulation guidelines", project report, Oct. 2013.

[EARTH23] EARTH project, "D2.3 - Energy efficiency analysis of the reference systems, areas of improvements and target breakdown," <https://www.ict-earth.eu/publications/publications.html>, Jan. 2012.

9.2.16 T3.2 TeC.16 Non-coherent communication in coordinated systems

This TeC investigates non-coherent multiple-input multiple-output (MIMO) communication, where data detection is carried out without any knowledge of the MIMO channel coefficients at the receiver side. The main focus is to evaluate the performance of non-coherent communication schemes in multi-point systems and also to propose novel transmission schemes intended for non-coherent multi-user (MU) communication. Among other contributions, we have proposed a MU transmission scheme based on superposition coding, where each user signal is transmitted with a different power sharing factor. At the receiver side, we showed that maximum likelihood (ML) detection of the superposed signals through exhaustive search has exponential complexity with the number of users. Hence, the ML detector is unfeasible even for a small number of users. In order to reduce the ML detection complexity, we developed a suboptimal MU receiver adapted to the superposition coding transmission scheme. It is important to note that, due to the fact that the channel coefficients are unknown, conventional successive interference cancellation is not feasible at each detection stage to remove the effect of previously detected user signals. Rather, we consider previously detected symbols within the detection rule. The key feature of the proposed receiver is that each user detects its own signal after previously detecting the signals of those users that are received with higher power than its own. In order to perform this successive detection, an approximated system model is considered at each step.

We assumed a transmission through block-fading Rayleigh channels, containing Gaussian i.i.d. elements with zero mean and unit variance. The performance of the proposed MU non-coherent communication scheme was obtained with the two investigated detectors: the proposed suboptimum non-coherent MU detector based on successive detection of users' signals and the ML exhaustive-search detector. Both MU non-coherent communication setups were also compared with a non-coherent user time division multiplexing (TDM) scheme. By varying the power sharing factors, we obtained the rate region in bits per channel use (bpcu) of the two-user MIMO channel for a fixed SNR value for both users equal to 10 dB. Figure 9.37 shows the resulting rate regions of the three evaluated schemes. It can be observed that the two setups carrying out non-coherent MU detection strongly outperform the TDM scheme in terms of sum-rate, proving the interest of MU non-coherent transmission.

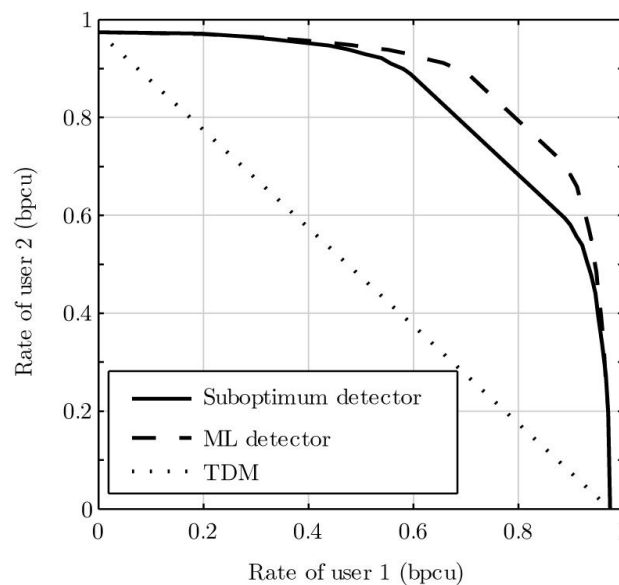


Figure 9.37: Rate region of a two-user non-coherent downlink communication using TDM, superposition coding with ML MU detection and superposition coding with the proposed MU detection.



9.2.16.1 Acronyms

MIMO	Multiple-Input Multiple-Output
MU	Multi-user
ML	Maximum Likelihood
TDM	Time-division multiplexing
bpcu	Bits per channel use

9.3 Preliminary Results for Task 3.3

9.3.1 T3.3 TeC.01 Coordinated multi-flow transmission for wireless backhaul

We consider first a reference scenario with wired backhaul in which terminals have fixed uplink/downlink rates. The main question is: *If the wired backhaul is removed, the rates of the terminals in uplink/downlink should stay the same and they are supported by wireless backhauling and network coding, then what is the minimal power that the base station should apply in order to achieve those rates?* Here we provide a numerical example of the wireless backhauling. In the example, we assume one BS with N antennas, two relays and two users, each with one antenna. In order to preserve identical rates with the wired backhaul, while assuming no change in the transmission power of the terminals, a relay station RS should be able to decode the signal from the BS by treating the signal from the MS as interference and then cancel the BS signal, such that the MS-RS channel is identical to the case of wired backhaul. The following beamforming methods at the BS are considered:

- BS broadcasts to the relays using ZF. This is shown in Figure 9.38 (left), where BS sends data x_{B1} to RS1, and x_{B2} to RS2. The beam towards RS1 nulls out RS2 and vice versa. Simultaneously, users U1 and U2 send their respective uplink data x_{U1} and x_{U2} .
- BS broadcasts one common beam, carrying a concatenated packet. This is shown in Figure 9.38 (right), where x_C is the concatenation of x_{B1} and x_{B2} . Here, we find both the optimal transmission power at the BS, and the optimal beamformer giving this power.

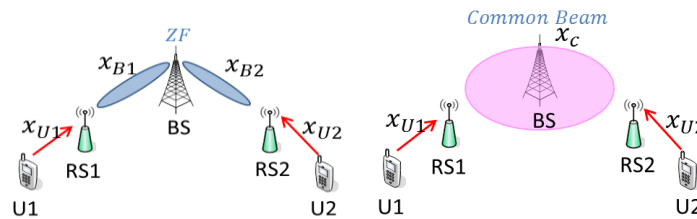


Figure 9.38: Considered schemes for broadcasting at the BS.

For the solution of the common beamforming, we use Semi Definite Programming (SDP) [GSS+10]. The comparison of these methods is shown in Figure 9.39, where we have fixed the uplink rate requirement of the two users to 0.5 bps. Bandwidth is normalized to 1 Hz. The downlink rate requirement ranges between 0.1 and 10.1 bps. The performance of the common beamforming is given by its lower bound. From the results, we can observe that there is a crossing point of the downlink rate. For downlink rates on the order of, or less than the uplink rate, the common beamforming method has superior performance, while for downlink rates much higher than the uplink rate, the ZF method has the best performance.

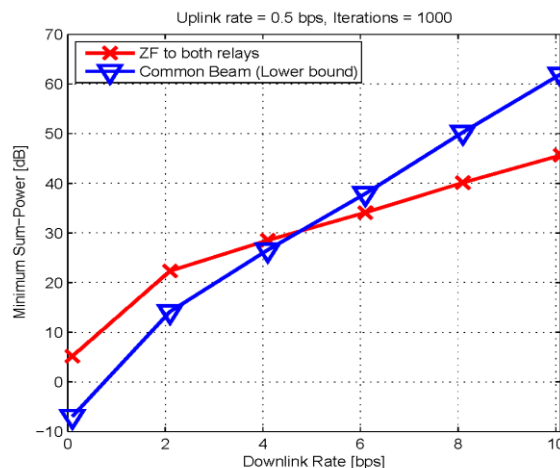


Figure 9.39: Performance Comparison of the beamforming methods.



9.3.1.1 Acronyms

AP	Access Point
BS	Base Station
RS	Relay Station
SDP	Semi Definite Programming
ZF	Zero Forcing

9.3.1.2 References

[GSS+10] A. B. Gershman, N. D. Sidiropoulos, S. Shahbazpanahi, M. Bengtsson, and B. Ottersten, "Convex optimization-based beamforming: From receive to transmit and network designs," IEEE Signal Process. Mag, 27(3), pp. 62-75, 2010.

9.3.2 T3.3 TeC.02 Interference aware routing and resource allocation in a millimetre-wave Ultra Dense Network

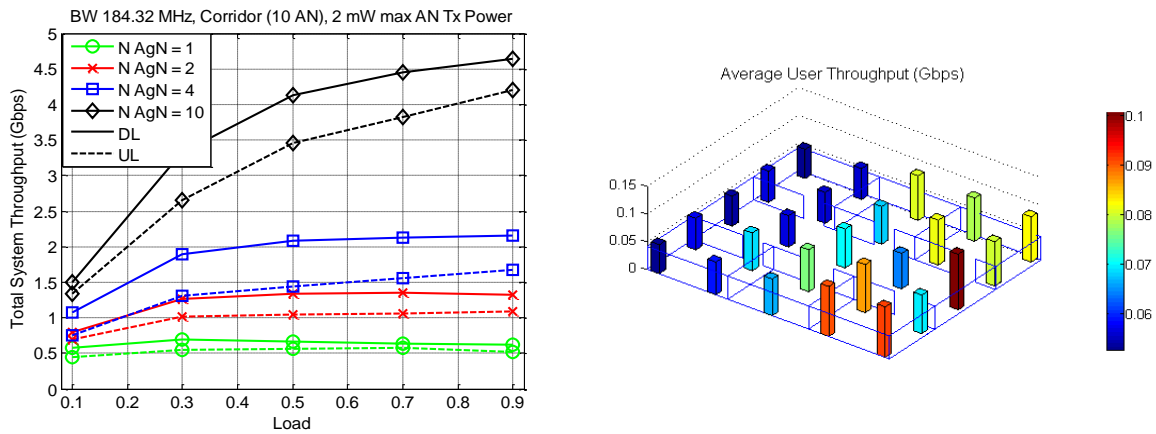


Figure 9.40: simulation results for T3.3 TeC.02

Figure 9.40 (left) illustrates system throughput as a function of load in an office floor plan UDN operating in the mmW region, when interference aware multi-hop native wireless backhaul routing and resource allocation is used. A load of 1.0 means an UL/DL-symmetric, on average one DL plus one UL full-buffer user per access node (AN). The different curves illustrate varying number fibre connected access points, acting as aggregation nodes (AgNs) towards external sources/destinations, out the of the 10 AN's in total.

A 3dB lower TX powers of devices as compared to AN's result in lower system throughput for UL than for DL, in particular when only few hops are required when AgN's are many and the Device-to-AN link comprise a more significant part of the total transmission power. It can, as expected, be observed that the AgN's sooner (for lower load) become the bottlenecks limiting the system throughput the fewer the AgN's there are. It can, however, also be observed that as the loads continue to increase, the increasing number of links in the air at higher load, does not significantly further limit the bottleneck link or the throughput of the system when the *interference aware* routing and resource allocation is used. A route diversity effect is observable as system performance continues to increase also above "full AgN load" (Load 0.1, 0.2, and 0.4 for 1 2 and 4 aggregation nodes respectively).

Figure 9.40 (right) illustrates the used floor plan with the average spatial throughput distribution over independent user drops in the case of a single AgN located slightly to the left of the centre of the south-east end of the corridor and a load of 0.9. The limited fairness in the routing/resource allocation scheme results in an overweight in user throughput towards the AgN.

Continued work is planned to increase fairness aspects and investigate benefits of adding more WLBH ANs to a given number of fibre connected AgNs. This is the question that will be faced with for UDN deployments, rather than that of connecting AN's with fibre or not.

9.3.2.1 Acronyms

mmW	Millimetre Wave
UDN	Ultra Dense Network
AN	Access Node
WLBH	Wireless backhaul
AgN	Aggregation Node

9.3.3 T3.3 TeC.03 Virtual full-duplex buffer-aided relaying

The main objective of this TeC is to recover a loss of multiplexing gain in HD relaying by allowing concurrent transmissions of a source and a relay among multiple relays, each of which equips buffer and multiple antennas. The key idea is joint beamforming design at each relay in order to mitigate/cancel IRI and opportunistic relay-pair selection in order to increase end-to-end achievable rate.

Figure 9.41 shows the spectral efficiency of various transmission schemes including a pure HD relay selection scheme without buffer (HD-BRS), HD BR schemes (HD-MMRS and HD-MLRS), conventional VFD-BR scheme with an IRI-free assumption (SFD-MMRS-IRI), and proposed VFD-BR schemes (Optimal BF, ZFBF, and SINR). In this simulation, we consider three relays ($K=3$) with four antennas ($M=4$) and assume i.i.d. Rayleigh block fading with the same average channel quality for all the links. While the proposed SINR-based VFD-BR scheme outperforms the conventional SFD-MMRS-IRI and HD relay selection schemes at low and medium SNRs, the proposed Optimal BF- and ZFBF-based VFD-BR schemes almost approach the upper bound without any loss in multiplexing gain, regardless of SNR. Note that the ZFBF-based VFD-BR scheme has much less complexity than the Optimal BF-based VFD-BR scheme with a marginal performance loss in this case.

Consequently, the proposed Optimal BF- and ZFBF-based VFD-BR schemes almost fully recover the loss of multiplexing gain caused by the HD relaying without a two-way traffic restriction assumed in network coding-based solutions. It implies that this TeC can provide almost double spectral efficiency compared to the HD relaying. Since the relaying communication inherently gives enhanced channel qualities due to reduced communication distances, this TeC can significantly increase the spectral efficiency of edge users.

Continued work is planned to apply this approach to other scenarios, which are more like a downlink scenario (e.g., a source with multiple antennas) and a multiple source-destination pairs scenario that can contribute to UDN deployments.

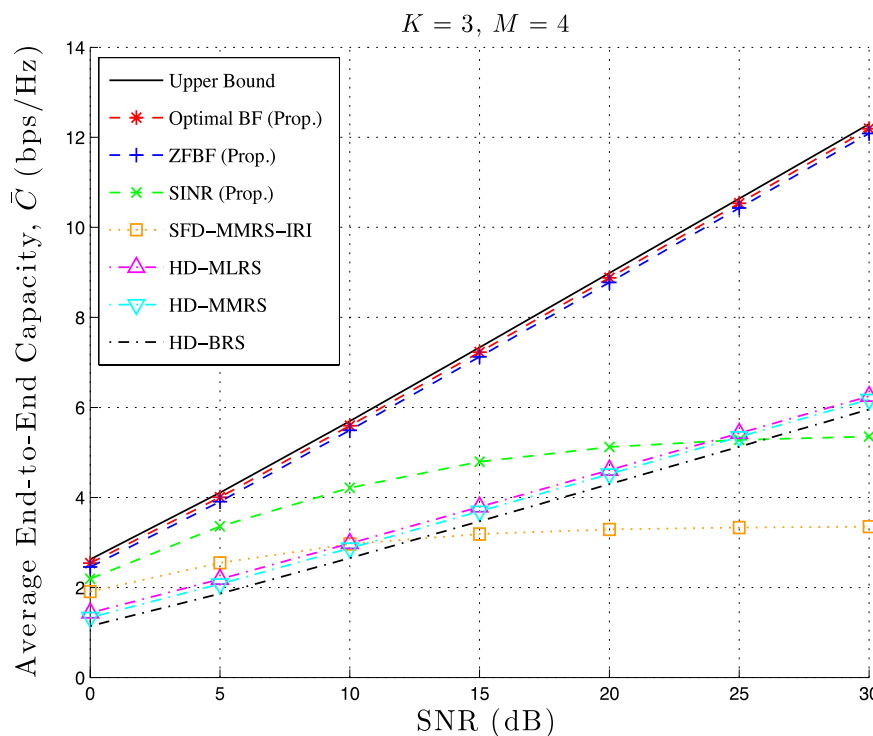


Figure 9.41: Spectral efficiency in a relay network including a source, a destination, and three relays ($K=3$) with four antennas ($M=4$) and buffer

9.3.3.1 Acronyms

BF BeamForming



BR	Buffer-aided Relaying
BRS	Best Relay Selection
FD	Full-Duplex
HD	Half-Duplex
IRI	Inter-Relay Interference
MMRS	Max-Max Relay Selection
MLRS	Max-Link Relay Selection
MMSE	Minimum Mean Square Error
MRC	Maximum Ratio Combining
MRT	Maximum Ratio Transmit
SFD	Space Full-Duplex
SINR	Signal-to-Interference-and-Noise-Ratio
SNR	Signal-to-Noise-Ratio
VFD	Virtual Full-Duplex
ZFBF	Zero-Forcing BeamForming
UDN	Ultra Dense Network

9.3.4 T3.3 TeC.04 Distributed coding for the multiple access multiple relay channel

In SO-MAMRC type I, only the sources transmit simultaneously during the first phase (listening phase of the relays), and only the relays transmit simultaneously during the second phase. We fix the number of sources to two, each source is provided by one transmit antenna, the transmission rate is fixed to 2/3 bit/ Hz/s. We vary the number of relays from zero to two, each relay is provided by one receive and one transmit antenna. The two sources use identical turbo codes of rate-1/2 made of two 4-state rate-1/2 RSC encoders with generator matrix $G_1 = [1 \ 5/7]$ in octal representation, whose half of the parity bits are punctured. The JNCC at the relays (when exist) is based on the network coding vectors chosen from MDS code, followed by a 4-state rate-1/2 RSC encoder with generator matrix $G_r = [1 \ 5/7]$.

The individual block Error Rate (BLER) is denoted by the function $BLER1(\gamma_{sd}, \gamma_{sr}, \gamma_{rd})$.

Figure 9.42 shows the individual outage probability $P_{out}(\gamma, \gamma, \gamma)$ and the individual BLER $BLER1(\gamma, \gamma, \gamma)$ when the number of receive antenna at the destination is $N_d = 1$.

We notice in general, that increasing the number of relays increase the diversity and our practical coding and encoding schemes is able to achieve this diversity for the different simulated cases.

Figure 9.42 shows that at a BLER of 0.01, one relay and two relays provide a considerable gain of 7 dB and 10 dB, respectively when there is no relay.

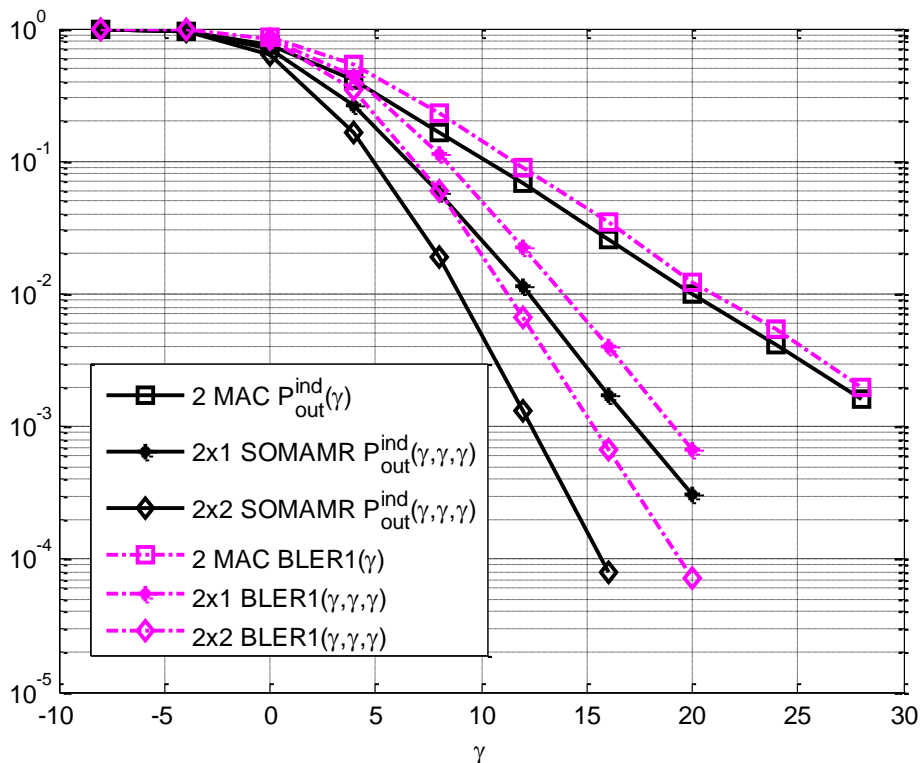


Figure 9.42: Individual BLER (e.g., for S_1) - Practical SOMAMRC/JNCC vs outage limit ($N_d = 1$).



9.3.4.1 Acronyms

MAMRC Multiple Access Multiple Relay Channel.

MAC Multiple Access Channel.

SO-MAMRC Semi Orthogonal Multiple Access Multiple Relay Channel.

BLER Block Error Rate

9.3.5 T3.3 TeC.05 Bi-directional relaying with non-orthogonal multiple access

One of the crucial parameters of the proposed system is the applied channel code. In this study Irregular Repeat Accumulate (IRA) codes [JKM00] have been proposed as they allow for a very flexible design at moderate complexity. A code design framework for IRA codes has been developed and IRA codes have been implemented into the general simulation framework.

Figure 9.43 exemplarily depicts the gain in spectral efficiency for the optimized IRA coded system with four nodes (i.e. two pairs, one common relay) compared to a conventionally coded system. For the conventionally coded system a serial concatenation of a (5,7) convolutional code and a repetition code are applied. For this code combination in the given system successful decoding starts around 5dB. Therefore, 5dB was chosen as working point for the optimized IRA coded system to keep the comparison fair. Note that the optimized system can be adjusted to any given working point which the conventionally coded system cannot due to the low number of degrees of freedom, i.e. the code rate of the regular repetition code. As can be seen in the figure, in the working point (5dB) a gain of approx. 43% in spectral efficiency can be observed.

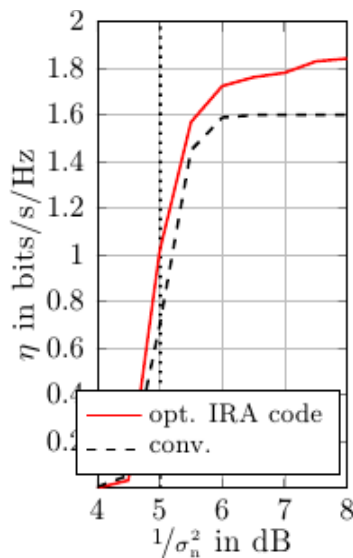


Figure 9.43: Spectral efficiency for the optimized IRA coded system for symmetric rate requirements.

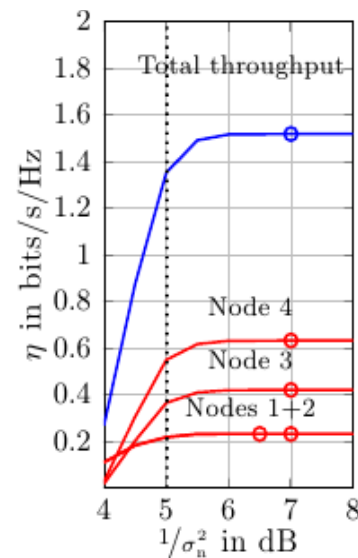


Figure 9.44: Per-node throughput for optimized system with asymmetric rate requirements.

Furthermore, the developed code design framework allows for an explicit consideration of per-node rate requirements. That means that relations of desired target rates can be explicitly formulated as a constraint for the code design. Figure 9.44 depicts the individual node throughputs of a designed system with per-node rate targets. Here, the desired rates have been arbitrarily chosen as $R_1=R$, $R_2=R$, $R_3=2R$, $R_4=3R$. As can be seen, the actual rates meet the target rates very well, especially asymptotically. In the design working point (5dB) some deviations are noticeable. This is caused by a simplification in the code design process as described in [LBW+13].

Concluding, the current results for the code optimization as one essential part of the overall system design look very promising. The next step of the planned research is the combination of the code design framework and power allocation methods, as power allocation plays an important role in the overall system performance and has a direct impact on the code design itself. Furthermore, different system setups have to be investigated in order to come to universally valid conclusions regarding the achievable performance gains.

9.3.5.1 Acronyms

IRA Irregular Repeat Accumulate



9.3.5.2 References

[JKM00] H. Jin, A. Khandekar and R. McEliece, "Irregular Repeat Accumulate Codes," Second International Symposium on Turbo Codes, Brest, France, Sept. 2000.

[LBW+13] F. Lenkeit, C. Bockelmann, D. Wübben and A. Dekorsy, "IRA Code Design for IDMA-based Multi-Pair Bidirectional Relaying Systems," International Workshop on Broadband Wireless Access (BWA 2013) co-located with IEEE Globecom 2013, Atlanta, GA, USA, 9-13 Dec. 2013.

9.3.6 T3.3 TeC.06 MIMO physical layer network coding based underlay D2D communication

We derived closed form solutions of the precoder decoder matrices for direct D2D communications. The algorithms and proofs are not presented in this document.

Numerical illustration assumes all channels to undergo Rayleigh fading. Entries of \mathbf{H}_{ij} are

assumed to be: $\frac{1}{d_{ij}^2} \text{CN}(0,1)$ where d_{ij} is the normalized distance between nodes. We

assume the BS is located in (0, 0), the MS is located in (1, 0), the RS is located in (0, -2), and the device D_1 is located in (-0.5, -2) in a XY grid. The device D_2 is assumed to have a uniform distribution along the grid. All noise variables are considered to have similar variance (σ^2). We also consider that the transmitted symbols are uniformly distributed.

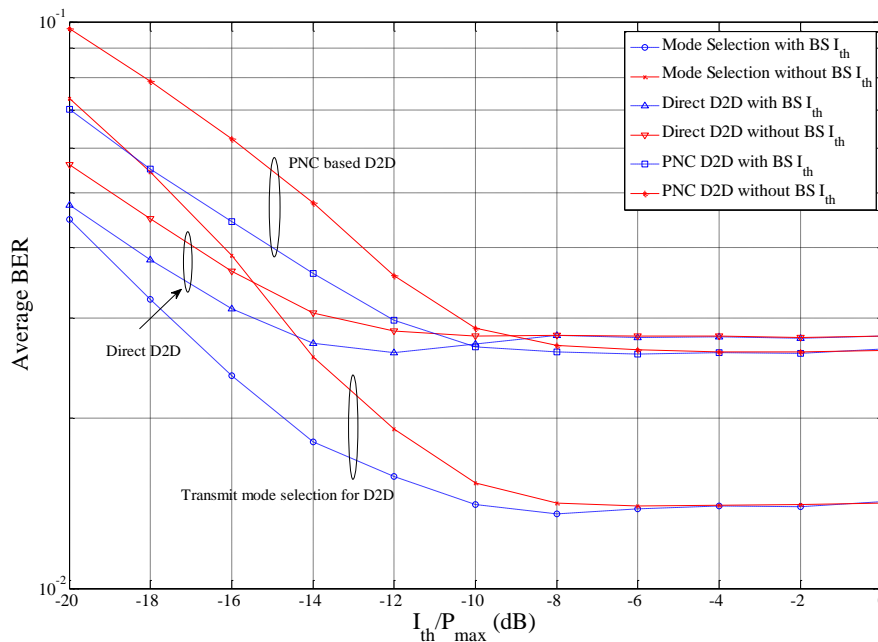


Figure 9.45: Average BER variation versus I_{th}/P_{max} . Number of antennas $N=2$ and $P_{max}/\sigma^2 = 19$ dB

In a scenario where both D2D modes are available for selection as the transmission mode, the proposed algorithms can be used together. Here, Figure 9.45 shows the scenario when D2D pair selects its transmitting mode in a given instance (depending on the CSI). This can be referred to as the dynamic mode selection scheme, where D2D pair selects the transmitting mode that gives the minimum total MSE (considering bidirectional flows in both D2D and BS-MS). We consider I_{th} as the interference threshold limit that all nodes can withstand to have stable communication. Therefore, the interference generated by the D2D communication should not exceed this limit. Similarly, maximum transmit power at all nodes have a limit of P_{max} . The average BER of all communications are considered with I_{th}/P_{max} when P_{max}/σ^2 is fixed at 19 dB. Two separate cases are considered for interference threshold limit at the BS-MS communication. For $I_{th}/P_{max} < -10$ dB, the direct D2D communication has lower ABER than the PLNC based D2D. Also, considering I_{th} limit at the BS-MS pair improves the ABER for all scenarios. However, the dynamic mode selection without considering I_{th} at the BS-MS pair has lower performance in some regions; this is possible since the selection is based on instantaneous total MSE, not on ABER.

In Figure 9.46, the dynamic mode selection scheme is analyzed with P_{max}/σ^2 when I_{th}/P_{max} is fixed at 7 dB. Here, the ABER improves with the P_{max}/σ^2 , and the dynamic mode selection in

the scenario with BS I_{th} performs better at high P_{max}/σ^2 . However, at the low P_{max}/σ^2 , the behavior is different. This is due to higher I_{th}/P_{max} ratio, and the selection is based on instantaneous total MSE. In such cases, the direct D2D mode performs better.

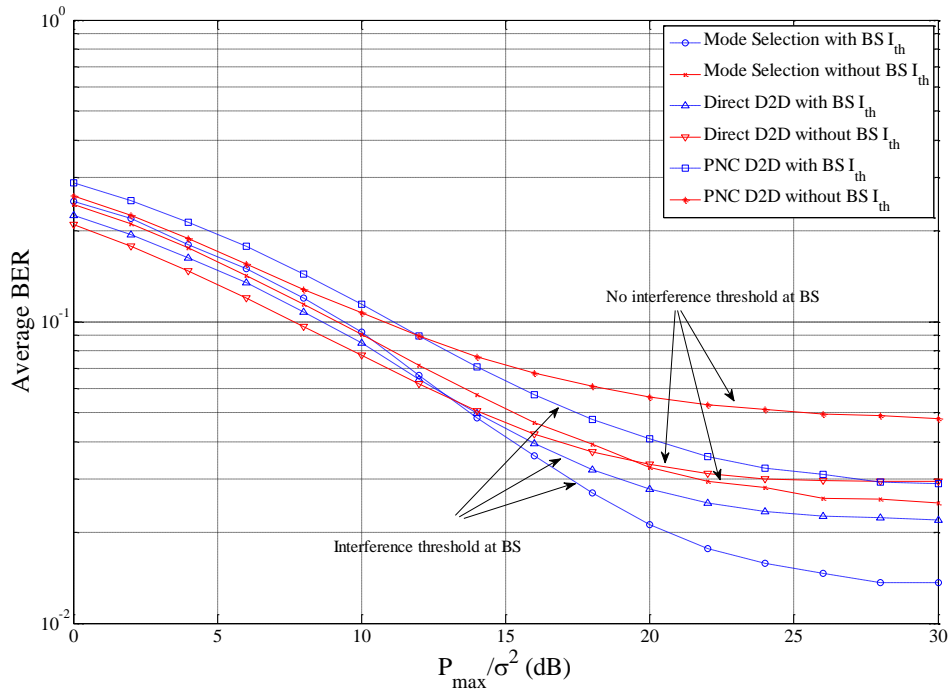


Figure 9.46: Average BER versus P_{max}/σ^2 . Number of antennas $N = 2$ and $P_{max}/I_{th} = 7$ dB

9.3.6.1 Acronyms

ABER	Average Bit Error Rate
BC	Broadcasting
BER	Bit Error Rate
BS	Base Station
CSI	Channel State Information
D2D	Device-to-device
MA	Multiple Access
MIMO	Multiple-Input Multiple-Output
MS	Mobile Station
MSE	Mean Square Error
PLNC	Physical Layer Network Coding
RS	Relay Station

9.3.7 T3.3 TeC.07 Cooperative D2D communications

The main objective behind the proposed scheme in this TeC is to allow cooperation between cellular links and direct device-to-device (D2D) communication links to increase the spectral efficiency, the cell throughput, the number of connected devices within the cell, and the cell coverage.

It is assumed that the D2D transmitter uses the decode-and-forward (DF) relaying protocol and operates in a half-duplex mode in which it cannot transmit and receive at the same time. The transmission scheme is the time division multiple access (TDMA) technique where the slot is divided between the base station and the D2D transmitter. The first time slot is used for transmission of the base station to transmit the signal of the cellular user. This signal is received by both the cellular user and the D2D transmitter. The signal is decoded and re-encoded by the D2D transmitter. In the next time slot, the D2D transmitter employs superposition coding in order to transmit a linear combination of its own signal and the signal of the cellular user. Here the D2D transmitter splits its power between the two signals. The power splitting should ensure that the link quality of the cellular user is not affected as compared to the regular direct link alone. The main objective is to try to maximize the data rate of the D2D link while ensuring the same or a better link for the cooperating cellular user. Hence, such a cooperation process has the potential to double the number of connections within the cell without any extra radio resources.

We evaluate the cooperation performance between cellular UEs (CUEs) and the D2D user, and the achievable gain of the D2D user in crowded environments for different system parameters by means of Monte-Carlo simulations. For our preliminary results, we assume a single hexagonal cell with radius R with base station placed in the corner of the cell. In each realization, M CUEs and one D2D pair are generated randomly uniformly distributed over the cell area. The distance of the D2D receiver from its transmitter lies in the range 20 to 50 meters. Both base station and D2D transmitter use their maximum power for transmission. The channel model accounts for the effects of path loss, multi-path fading, and shadowing. The path loss model is taken from [XH10]. We use the same shadowing variance for line-of-sight and non-line-of-sight channels.

Figure 9.47 shows the achievable data rates for both cooperative cellular and D2D users when $R = 500$ m and $M = 20$. In case of cooperation in our model, the cooperative CUE always achieves the direct link data rate while the D2D user can also transmit with high data rate. The cooperative D2D communications not only provide opportunities for transmission in high density areas, but also a high data rate for the D2D user leading to an increase in cell capacity.

Note that our problem is modelled in a way that the CUE achieves at least its direct link rate. This is beneficial in cases that the network is overloaded in crowded areas. If cooperation should be used as a mean of capacity improvement in bad spots, an extra capacity gain for cellular user should be defined, i.e., the CUE should achieve at least its direct link rate multiplied by the required gain factor. This is possible, as seen in Figure 9.47, since the achieved data rate of the D2D link is quite high and investing more power to the cellular user should be possible. More results can be found in [SB14].

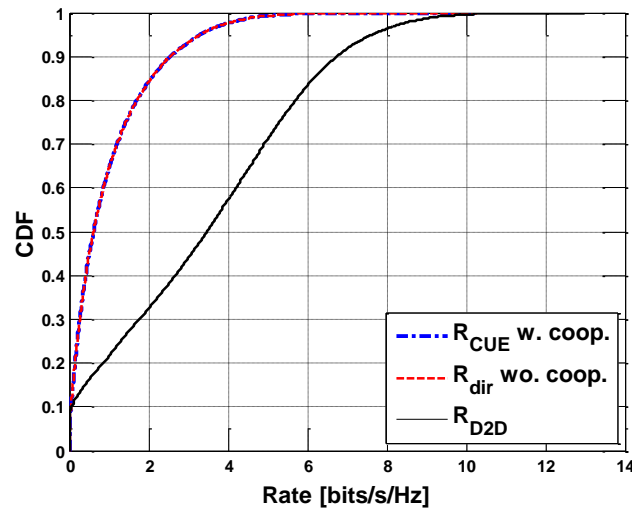


Figure 9.47: CDF of data rates when $R = 500$ m and $M=20$.

9.3.7.1 Acronyms

D2D	Device-to-device
CUE	Cellular user equipment
TDMA	Time division multiple access
DF	Decode-and-forward

9.3.7.2 References

[XH10] H. Xing and S. Hakola, "The investigation of power control schemes for a device-to-device communication integrated into OFDMA cellular system," in Proc. IEEE PIMRC '2010, Istanbul, Turkey, pp. 1775–1780, September 2010.

[SB14] S Shalmashi and S. Ben Slimane, "Cooperative device-to-device communications in the downlink of cellular networks," to appear in IEEE WCNC '2014, Istanbul, Turkey, 6-9 April 2014.

9.3.8 T3.3 TeC.08 Open-loop techniques in a network with D2D relaying

This TeC considers wireless relay networks with multi-antenna user equipment (UE) relays. Taking into account the generally open-loop relaying operation of UE relays, a multi-functional multiple-input multiple-output (MIMO) scheme that combines group-wise space-time coding (STC) with directional beamforming is implemented in a cooperative fashion.

For the performance evaluation, we considered a downlink communication where $K=2$ UE relays are in the straight line between base station (BS) and destination, at a normalized distance from BS equal to $d=0.5$. The Alamouti code was selected for the STC groups. Both relays were at the same distance from BS but experienced independent fading. We assumed a block-fading Rayleigh channel, containing Gaussian i.i.d. elements with zero mean and unit variance. Distance-dependent pathloss was further included. The total transmitted power from the source and from the relays was considered the same, equal to η and shared uniformly by the relays. First evaluations showed that including beamforming at either the BS or relays can strongly enhance the performance of the multi-functional transmission, in comparison with a direct transmission from the BS with the same transmitted power. However, beamforming at the relays was only beneficial when the relays were closer to the BS than to the destination. It was also shown that beamforming could compensate the multiplexing loss at low transmission rates. However, as the modulation order was increased, a multi-functional scheme based on only group-wise STC was more advantageous.

Figure 9.48 shows the bit error rate (BER) curves vs transmitted power for the proposed multi-functional scheme based on group-wise STC. A quasi-orthogonal space-time block code (QOSTBC) scheme for relays jointly designed for the same total number of transmit antennas was also included as a baseline. In this example, $M=4$ constellation symbols per block were transmitted, but a constellation of double bits per symbol was considered for the QOSTBC to make both schemes comparable in terms of transmitted rate. Beamforming gain was not here considered. In Figure 9.48(a), the QOSTBC-based setup with QPSK symbols outperforms the Alamouti-based group-wise setup with BPSK. However, the opposite happens in Figure 9.48(b), where the group-wise setup with QPSK is more advantageous than the QOSTBC with 16QAM. The reason is that a linear increase in the modulation order generally entails a non-linear increase in the SNR to fulfil a given BER objective. Therefore, the higher coding gain of QOSTBC does not compensate the use of a constellation of double bits per symbol at high transmission rates. Figure 9.48(b) also reveals that the performance enhancement of group-wise STC is more pronounced ($\approx 3\text{dB}$) in the relayed scheme without availability of the direct link.

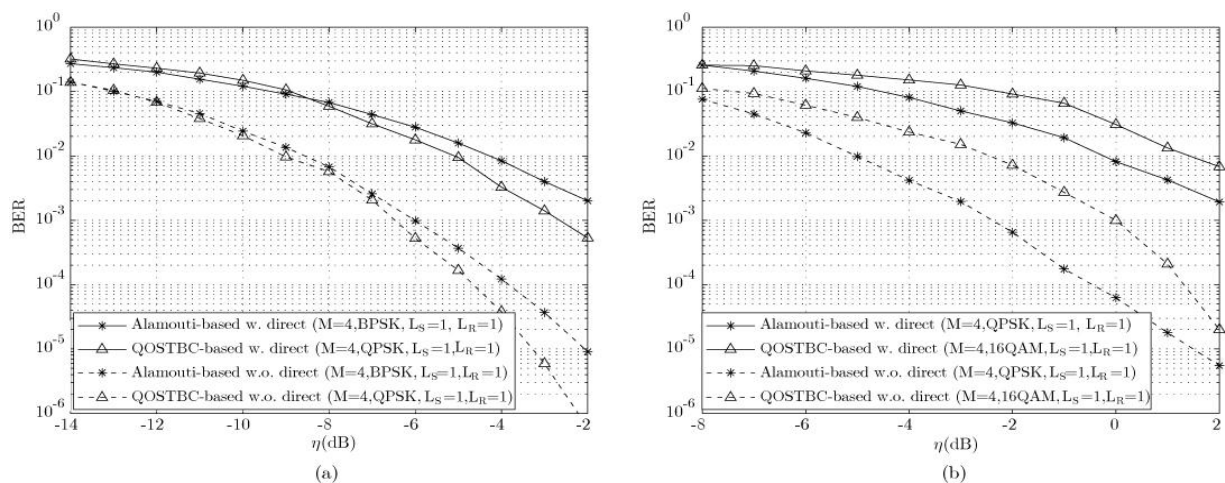


Figure 9.48: BER comparison between multi-functional MIMO based on group-wise STC and QOSTBC transmission using 4 transmit antennas, both evaluated with and without availability of the direct link: (a) With BPSK and QPSK, (b) with QPSK and 16QAM.



9.3.8.1 Acronyms

BER	Bit error rate
BPSK	Binary Phase Shift Keying
BS	Base station
MIMO	Multiple-input multiple-output
QAM	Quadrature Amplitude Modulation
QOSTBC	Quasi-orthogonal space-time block coding
QPSK	Quadrature Phase Shift Keying
STC	Space-time coding
UE	User equipment

9.3.9 T3.3 TeC.09 Uplink enhancement of vehicular users by using D2D communications

We evaluate the energy efficiency performance of the considered schemes by using system level evaluations. The employed evaluation parameters are based on [3GPP11-25996], [3GPP13-R1130925], and are summarized in Table 9.4. Vehicular UEs (VUEs) are located inside a public transportation vehicle, and several of the VUEs need to send data to the BS. Only VUEs that require uplink communication are assumed to participate in the cooperation. This is a realistic assumption, as it is difficult to motivate that idle VUEs with no communication should participate in the cooperation. Each of the VUEs could communicate with the BS directly (baseline case), or different number of VUEs can cooperate with each other by using D2D communications. In cooperation, based on the size of an average city bus, we assume a maximum distance of 5 meters between the two furthest VUEs participants. One physical resource block (PRB), which is the smallest scheduling grant, is used for the VUE-to-BS communication, and 10 PRBs are allocated for the D2D communication. This is motivated by the fact that user devices are usually limited by their transmit power, and in practical systems, e.g, the LTE system, user devices can concentrate their power in a small bandwidth to maximize the coverage [STM11, Ch. 18]. However, compared to VUE-to-BS communication, for D2D communication, as VUEs are located near to each other, the communication is unlikely to be limited by power. Thus, wider bandwidth and lower transmit power is assumed in this study for D2D communication.

Table 9.4: Simulation Parameters

Parameter	Value
Carrier frequency	2.6 GHz
Cell radius	866 meters
VUE to BS pathloss model	$L_{dB} = 39.1 + 35.1 \log_{10}(d)$
D2D pathloss model	$L_{dB} = 41.1 + 16.9 \log_{10}(d_{UE})$
D2D fading margin	20 dB
VUE to BS transmit power	23 dBm
D2D transmit power	10 dBm
Receiver noise figure at the BS	5 dB
Receiver noise figure at the VUE	9 dB
PRB size	180 kHz
Traffic model	Full buffer

Figure 9.49 and Figure 9.50 plot the average expanded energy per information bit when different numbers of VUEs cooperate with each other in the cases of Vehicle Penetration Loss (VPL) equal to 20 dB, and 30 dB. As we can see from both figures, for the cooperative transmissions, the more VUEs participate in the cooperation, the lower the energy spent on the communication. However, when VPL is 20 dB, the individual direct communication of each VUE with the BS costs less energy than the cooperating transmission. This is because the energy saved by the VUE cooperation is less than the energy overhead introduced by the D2D communication.

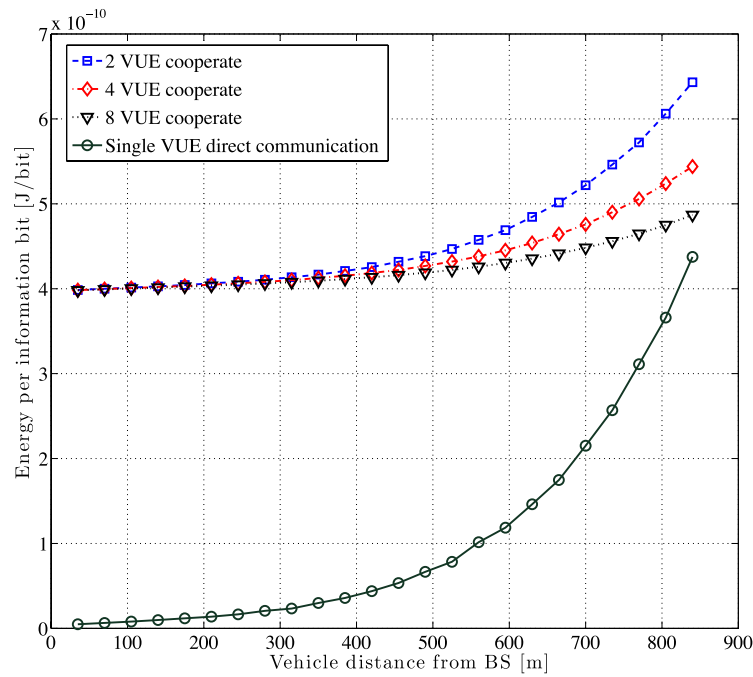


Figure 9.49: Energy per information bit when VPL = 20 dB

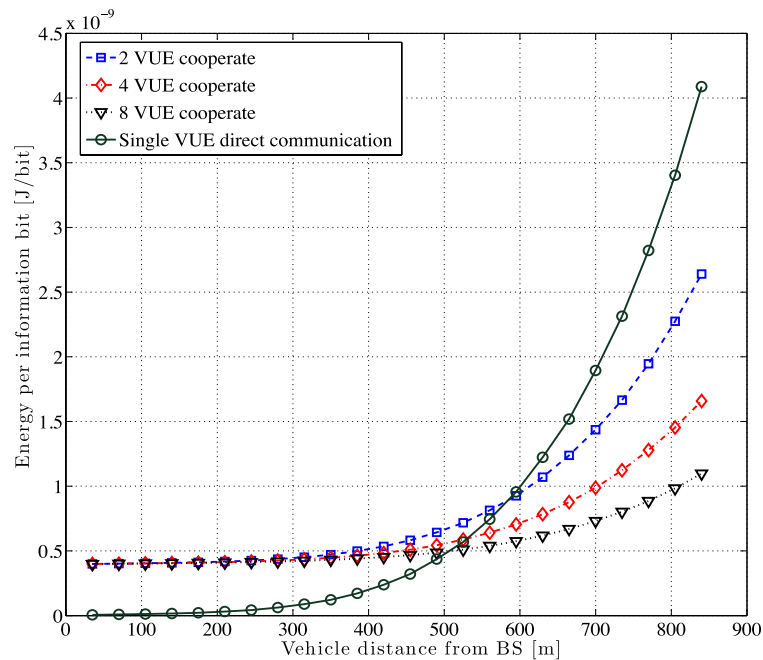


Figure 9.50: Energy per information bit when VPL = 30 dB

Nevertheless, when the communication is affected by higher VPL, i.e., 30 dB, the energy saving of using VUE cooperation can be observed, as the public transportation vehicle is moving away from the BS. This is due to the fact that VUEs are power limited for uplink communications. When the VPL is high, the communications are conducted in a power-limited region, and therefore even if two VUEs cooperate, it results in a significant increase of data rate. Thus, in this case all active VUEs can send their data faster, and spend less energy in total even when including the overhead caused by D2D communication.



9.3.9.1 Acronyms

BS	Base Station
D2D	Device to Device
PRB	Physical Resource Block
VPL	Vehicle Penetration Loss
VUE	Vehicular User Equipment

9.3.9.2 References

[Lo99] T. Lo, "Maximum ratio transmission," IEEE Trans. Commun, vol. 47, pp. 1458–1461, Oct. 1999.

[LHW07] S.Liu, Z.He,and W.Wu, "Transmit diversity method with user's power constraint for distributed antenna system," in Proc. 2nd ISWPC 2007.

[LNC+09] J. Lee, R. Nabar, J. Choi, and H.-L. Lou, "Generalized co-phasing for multiple transmit and receive antennas," IEEE Trans. Wireless Comm., vol. 8, pp. 1649–1654, Apr. 2009.

[ST13] Y. Sui, and T. Svensson, "Uplink Enhancement of Vehicular Users by Using D2D Communications", in Proc. IEEE Globecom workshop, 2013.

[3GPP11-25996] 3GPP TR 25.996, "Spatial channel model for Multiple In- put Multiple Output (MIMO) simulations", 2011.

[3GPP13-R1130925] Intel Corporation, "3GPP R1-130925, evaluation methodology for d2d discovery," 2013.

[STM11] S. Sesia, I. Toufik, and M. Baker, LTE-The UMTS Long Term Evolution: From Theory to Practice, 2nd ed. John Wiley & Sons Ltd., 2011.

9.3.10 T3.3 TeC.10 Combining physical layer network coding and MIMO for TDD wireless systems with relaying

In this TeC the two-phase two-way relaying scheme was investigated. The main focus was put on the second phase, where two different schemes were compared: network coding and MU-MIMO. In the network coding solution encoded modulo-2 sum of two messages was transmitted by the RS whereas in the case of MU-MIMO transmitted signal was a linear combination of two physical signals. In the proposed MU-MIMO scheme several precoding algorithms were compared such as Zero Forcing Beamforming (ZFBF) [KCK08] [HHJ02], Block Diagonalization (BD), Multi-user Block Diagonalization Beamforming (MU-BDBF) [CM04] and Singular Value Decomposition (SVD) algorithm (proposed by the authors for two-way relaying scheme).

The performance of the multiple antenna NC scheme together with the proposed MU-MIMO transmission protocol was presented as a result of multi-link level simulations. Two-way relaying in the system with basic features of the LTE system was modelled. Three different modulation schemes (QPSK, 16QAM and 64QAM) were applied in both transmission directions in which OFDM and SC-FDMA symbols were generated. Two different radio channel fading models were used: EPA 5 Hz (Extended Pedestrian A Model) and ETU 70 Hz (Extended Typical Urban A Model).

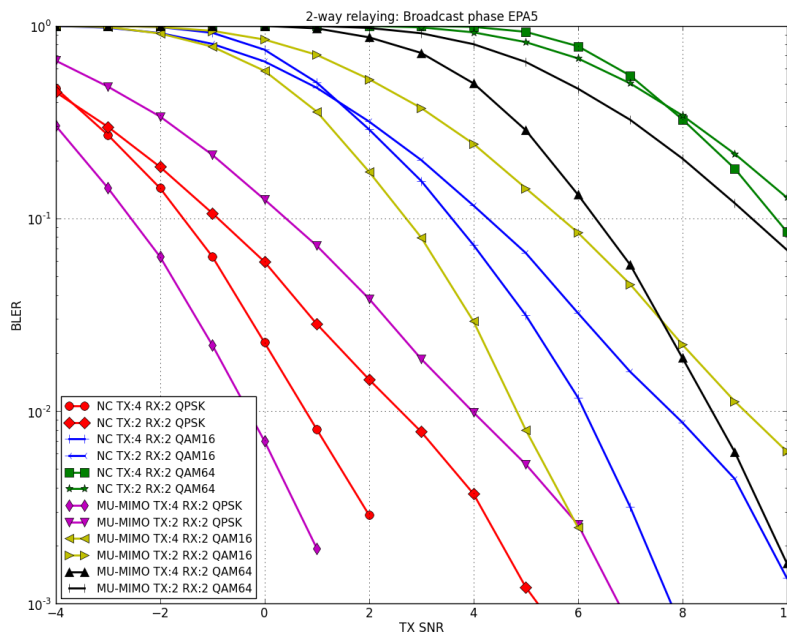


Figure 9.51: NC and MU-MIMO comparison (EPA 5 Hz, 4x2, limited feedback scenario)

The MU-MIMO precoders comparison have shown that the proposed MU-MIMO scheme with SVD precoding and interference cancellation receiver outperforms the BD, MU-BDBF and the ZFBF algorithms. The comparison of network coding and MU-MIMO with codebook-based SVD precoding algorithm is presented in Figure 9.51. The link from RS to BS is denoted as UL and the one from RS to MS as DL. It can be seen that the network coding performance is worse than the performance of the proposed SVD algorithm in the case of four transmit antennas for all modulation schemes. For two transmit antennas, NC performs better than MU-MIMO for QPSK and 16QAM. For 64QAM modulation MU-MIMO always performs better than NC.

9.3.10.1 Acronyms

BD Block Diagonalization



BS	Base Station
EPA	Extended Pedestrian A Model
ETU	Extended Typical Urban A Model
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MS	Mobile Station
MU-BDBF	Multi-user Block Diagonalization Beamforming
MU-MIMO	Multi-user MIMO
NC	Network Coding
RS	Relay Station
SVD	Singular Value Decomposition
ZFBF	Zero Forcing Beamforming

9.3.10.2 References

[KCK08] M. Kountouris, L. Cardoso, R. Knopp, "Capacity of linear multi-user MIMO precoding schemes with measured channel data," IEEE 9th Workshop on Signal Processing Advances in Wireless Communications, July 2008.

[HHJ02] T. Haustein, C. von Helmolt, E. Jorswieck, "Performance of MIMO systems with channel inversion," Proceedings of the 55th IEEE Vehicular Technology Conference (VTC'02), vol. 1, pp. 35-39, 2002.

[CM04] L.-U. Choi, R.D. Murch, "A transmit preprocessing technique for multiuser MIMO systems using a decomposition approach," IEEE Transactions on Wireless Communications, vol. 3, no. 1, pp. 20-24, 2004.