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Final CG "metropolitan area" description for integration into overall System Concept and assessment of key technologies

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Abstract:
This document presents the system design results for the Metropolitan Area deployments of WINNER system concept, and the associated performance assessment results. The focus of the work has been on items for which the special features of system deployments in these environments are especially challenging.

Keyword list:

Wideband mobile communications, system deployment, metropolitan area

Disclaimer:

Executive Summary

WINNER project develops a new radio access system concept which aims at providing wireless access for a wide range of services and applications across wide range of radio environments and deployment scenarios, with one single adaptive system concept. The design of such flexible and ubiquitous radio access system requires the joint optimisation of most advanced techniques in the digital communication domain, including most of the physical layer and radio resource management techniques.

The goal of the Concept Groups is to coordinate the definition of specific sets of operating parameters and algorithms suited to specific deployments. Three concept groups have been defined, devoted to Wide Area, Metropolitan Area and Local Area deployments, respectively. This deliverable addresses the metropolitan area scenario and introduces the system design results derived for metropolitan area deployments, targeted to the final WINNER system concept.

This deliverable provides results on system design and performance assessment for metropolitan area system deployments. The main results include:

- Proposed spatio-temporal processing methods with performance analysis for metropolitan area deployments
- an overview of WINNER relaying concept for metropolitan area deployments of the system, and detailed results on relay deployments in metropolitan areas; cooperative relaying for metropolitan area deployments; cost analysis case study of a relay based deployment in a metropolitan area scenario
- an overview of spectrum technologies, including spectrum sharing and flexible spectrum use, and their utilisation in metropolitan area deployments
- techniques for network synchronisation, multi-mode handover, interference mitigation and multiuser scheduling for metropolitan area deployments

Some of the system design results obtained within the project are valid for all the three concept groups. Thus results relevant from metropolitan area deployment point-of-view can also be found from the other concept group deliverables [WIN2D61310] and [WIN2D61312].

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List of Acronyms and Abbreviations

ARQ	Automatic Repeat Request (packet retransmission)
BER	Bit Error Rate
B-EFDMA	Block-Equidistant Frequency Division Multiple Access
B-IFDMA	Block-Interleaved Frequency Division Multiple Access
BS	Base Station
CAPEX	CAPital EXpenditure
CDF	Cumulative Distribution Function
CE	Channel Estimation
CG	(WINNER) Concept Group
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CSI	Channel State Information
CTF	Channel Transfer Function
DAC	Contention-based direct access (uplink) transport channel, now denoted TDAC
DL	Downlink
FD	Frequency Domain
FD-CTF	Frequency-Domain Channel Transfer Function
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FDT	Frame Description Table
FFT	Fast Fourier Transform
FEC	Forward Error Correction
GA-JCEMUD	Genetic Algorithm aided Joint Channel Estimation and Multi-User Detection
GA	Genetic Algorithm
GMC	Generalised Multi Carrier
GPS	Global Positioning System
GW_{LN}	Gateway logical node
HARQ	Hybrid Automatic Repeat reQuest
IFDMA	Interleaved Frequency Division Multiple Access, also denoted FDOSS
IFFT	Inverse Fast Fourier Transform
IRC	Interference Rejection Combining
L2	Layer 2
LA	Local Area
LDC	Linear Dispersion Code
LDPC	Low Density Parity Check (codes)
LOS	Line Of Sight
LP	Linear Precoding
MA	Metropolitan Area
MAC	Medium Access Control
MBMS	Multimedia Broadcast-Multicast Services
MC-CDMA	Multicarrier-Code-Division Multiple Access
MIMO	Multiple-Input Multiple-Output
ML	Maximum Likelihood
MMSE	Minimum Mean Square Error
MRC	Maximum Ratio Combining
MSE	Mean Square Error
MU	Multi-User
MUD	Multi-User Detection
MUI	Multiple User Interference
MUX	Multiplexing

NLOS	Non Line Of Sight
OF	Objective Function
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OHRSA	Optimised Hierarchy Reduced Search Algorithm
OPEX	OPerational EXpenditure
PACE	Pilot Aided Channel Estimation
PARC	Per Antenna Rate Control
PER	Packet Error Rate
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAC	Random Access Channel, transport channel now denoted TRAC
RAN	Radio Access Network
RAP	Radio Access Point
RBD	Regularised Block Diagonalisation
REC	Relay Enhanced Cell
RF	Radio Frequency
RLC	Radio Link Control layer
RN	Relay Node
RRM	Radio Resource Management
RTT	Round Trip Time
Rx	Receive
SDD	Space Division Duplex
SDMA	Spatial Division Multiple Access
SIC	Successive Interference Cancellation
SIMO	Single-Input Multiple-Output
SiSo	Soft-input Soft-output
SISO	Single-Input Single-Output
SINR	Signal to Interference plus Noise Ratio
SMMSE	Successive Minimum Mean Square Error
STBC	Space Time Block Coding
SU	Single User
SVD	Singular Value Decomposition
TBCH	Broadcast Transport Channel
TD	Time Domain
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
Tx	Transmit
UL	Uplink
UT	User Terminal
V-BLAST	Vertical Bell labs LAyered Space Time
WA	Wide Area
ZF	Zero Forcing

List of Mathematical Symbols

Δf	Subcarrier distance
f_c	Carrier frequency
T_G	Guard interval/cyclic prefix duration
T_N	OFDM symbol duration (without guard)/single carrier block length
λ	wavelength
β	pulse roll-off factor
$\theta_{3\text{dB}}$	3dB beamwidth of antenna element pattern

1. Introduction

The three concept groups in WINNER project, namely Wide Area (WA), Metropolitan Area (MA), and Local Area (LA), have two main goals in their activities. First, their work targets to ensure the end-to-end radio system design fulfilling the general goals set for the WINNER system, and second, they coordinate the proof of concept work, i.e. evaluation of the WINNER system in various predefined system deployment scenarios which resemble the environments and scenarios where WINNER system is envisioned to be deployed. Concept groups also highlight the novel areas that will differentiate WINNER system from current or known forthcoming future wireless communication systems.

This deliverable captures the WINNER system design from metropolitan area system deployment point of view. It is based on contributions from technical design areas to topics which are relevant to this deployment scenario. Some elements of the metropolitan area system design are identical to those used in the designs for wide area or local area concept groups. In order to avoid duplication, such parts are described in more detail in the wide area and local area deliverables [WIN2D61310], [WIN2D61312]. Cross-referencing is used to identify the sections in these deliverables which has relevance also from metropolitan area concept group point-of-view.

The structure of the deliverable is the following. Section 2 provides an overview of the metropolitan area deployment scenario, and lists the basic assumptions utilized in the system design and performance assessment work targeting this deployment scenario. Section 3 captures the system design results targeting to metropolitan area deployments. These results include solutions for spatio-temporal processing, relaying, multi-mode handover, spectrum functionalities, and network synchronisation. Section 4 collects the associated performance assessment results for the system design solutions presented in section 3. Section 5 provides the conclusions for this deliverable, and section 6 collects the references used in the deliverable. The included appendices provide some supporting details for sections 3 and 4.

2. Metropolitan area deployment

2.1 General

Dense urban, metropolitan environments, like those presented in Figure 2-1, pose several non-trivial challenges for deployment of wireless communication systems. These challenges are created by high user density and high traffic demand in urban areas, combined with difficult radio propagation and shadowing environments due to severe blocking of transmitted signals caused by the high-rise buildings, typically built according to a tight city plan.

Figure 2-1: Typical metropolitan area environment.

The so called "Manhattan grid", shown in Figure 2-2, is a straight-forward and best known layout used for modelling dense urban environments for performance assessment of wireless communication systems [ETSI1]. Manhattan grid models urban environment as a rectangular grid of streets and buildings, which in its' simplicity captures the most relevant characteristics of these environments. The parameterisation of Manhattan grid utilised in concept group metropolitan area is given in Chapter 2.2, and in [WIN2D6137].

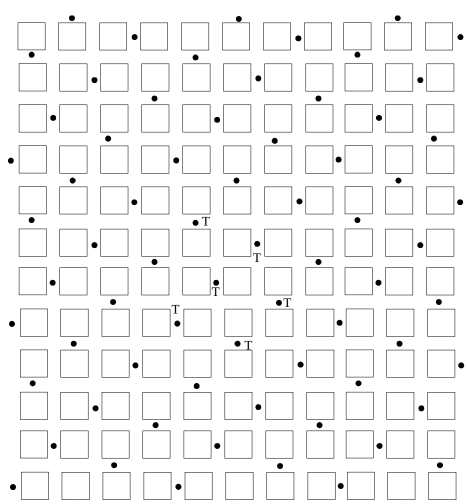

Figure 2-2: Manhattan grid.

The most important implication of metropolitan areas to a wireless communication system includes high user density in the coverage area, which results to high system throughput demand. The support for contiguous coverage, especially outdoors, is also very important for metropolitan area system deployments. As the number of potential indoor users is usually significantly high in metropolitan areas, the system deployment should support providing (at least partial) indoor coverage with the outdoor system deployment. Due to these demands, the metropolitan area deployments focus on microcellular system deployments. In practice this means that the base station and relay node antennas are placed in the street canyons, below the rooftop level.

Wireless communication system deployment in Manhattan grid has some special features when compared to other WINNER deployment scenarios:

- Many of the (outdoor) users are in line-of-sight (LOS) connection to base station or relay node. As the cell size is reasonably small, this means that these users are having very good channel condition (high signal-to-noise-ratio with only minor fluctuation of signal quality).
- Users that do not have LOS connection have significantly worse channel state. These users are located in streets where there are no base stations (or relay nodes), i.e. the base station is “around the corner”, or they are indoor users served by outdoor BS/RN. The propagation loss in the “around the corner” case, or in outdoor-to-indoor penetration through exterior walls is higher on the WINNER target carrier frequencies (from 3.2 to 5 GHz) than for the current wireless systems (like WCDMA). This means that the link budgets for these users can be limited resulting to limited data rates that can be offered to them.
- Due to the above-mentioned signal propagation issues, the changes in signal quality or interference level seen by a user can be very fast and significant.
- The mobility of the users is limited. Large fraction of the users is stationary or is moving in pedestrian velocities. The maximum mobility is up to allowed vehicle speed in urban environments (approximately up to 50 km/h).

For successful operation in metropolitan areas, WINNER system needs to provide solutions that take these special features into account.

The main challenges in metropolitan area system deployments include the above-mentioned issues with link budget and interference management. Due to these issues one major question is related to the system deployment costs in metropolitan areas. The system design solutions developed for metropolitan area must facilitate large enough cell and relay enhanced cell sizes in order to keep the deployment costs reasonable.

2.2 Details on the deployment scenario

The metropolitan area deployment scenario is described in detail in [WIN2D6137]. As the performance assessment results in chapter 4 utilise these parameterisations implicitly, they are repeated also here.

The environment specific working assumptions are listed in Table 2-1. As already mentioned the Manhattan grid is used as the basis for modelling for metropolitan area environments. The presented parameterisations are reflecting a typical metropolitan area.

	Microcellular deployment in metropolitan areas
Environment characteristics	Two-dimensional regular grid of buildings ("Manhattan grid") Number of buildings: 11 x 11 Building block size: 200 m x 200 m Street width: 30 m
User distribution model (at simulation start-up)	Number of users is a variable parameters All users are uniformly distributed on the streets (outdoor UT simulations) All users are uniformly distributed in the buildings (indoor UT simulations)
User mobility model (class III and IV)	• Fixed and identical speed $\|v\|$ of all UTs • $\|v\| \in \{3, 50\text{km/h}\}$ $\angle v$: UTs only move along the streets they are in. Direction is random and both directions are equally probable
User mobility model (simulator class I and II)	See [WIN1D72] (Typical Urban B1)
User traffic model (simulator class III)	Single traffic flow per user; Full queue per user or see Appendix A of [WIN2D6137]
User traffic model (simulator class I and II)	See Appendix A of [WIN2D6137]

Table 2-1: Environment specific parameterisations, and their modelling in simulators.

Table 2-2 presents further details of the deployment parameterisations in metropolitan area scenarios. While it was decided that FDD is assessed in wide area deployments, it was decided that TDD is assess in the metropolitan and local area deployments. Carrier frequency was selected to be close to the middle of the WINNER target frequency bands to obtain representative results, whatever the outcome WRC'07 will be. As the channel bandwidth, the maximum envisaged bandwidth of 100 MHz was selected to be used in the assessment work. Reasonably low values have been selected for the transmit power levels of base stations and relay nodes, so that flexible placement of these would be possible. Also other parameters reflect the below rooftop level (microcellular) deployment that is to large extent mandated by the difficult propagation environment.

		Microcellular
general	duplexing (asymmetry)	TDD (1:1)
	carrier frequency f_c	3.95 GHz
	channel bandwidth	100 MHz
	Deployment (see Figures 3.1 – 3.3)	cellular, Manhattan grid layout [ETSI1]
	location/height	Below rooftop, 10 m
	max. transmit power per sector	37 dBm = 5.012 W
	inter-site distance (only BS layout)	follows from Figure 2-2 and Table 2-1
	number of sectors per BS site	2
	number of antennas per sector	4
	antenna configuration (per sector)	Cross polarised linear array X X
	antenna element spacing	$0.5\lambda=0.5c/f_c$ (f_c =DL carrier frequency, c=speed of light)

		Microcellular
	azimuth antenna element pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ [dB] A_m= 20, θ_{3dB}= 70° (A_m= 23, θ_{3dB}= 35° for 6 sector site)
	antenna gain	14 dBi
	receiver noise figure	5 dB
user terminal	height	1.5 m
	transmit power	24 dBm = 251.2 mW
	number of antennas	2
	antenna configuration	dual cross polarised antennas: X
	azimuth antenna element pattern	$A(\theta) = 0\,\text{dB}$
	antenna gain	0 dBi
	receiver noise figure	7 dB
relay node	location/height	Below rooftop, 10 m
	max. transmit power per sector	30 dBm = 1 W
	number of sectors per RN site	1
	number of antennas per sector	1
	antenna configuration (per sector)	single antenna with omni directional pattern
	antenna element spacing	N/A
	azimuth antenna element pattern	Omni directional
	elevation antenna gain	7 dBi
	receiver noise figure	5 dB

Table 2-2: Metropolitan area system deployment specific parameters.

2.3 Channel models

Channel models used in Metropolitan Area are shown in Table 2-3. Channel parameters used in the simulations can be found in WINNER II deliverable [WIN2D111] describing the WINNER II interim channel models. (Slightly updated final versions can be found in [WIN2D112].).

Scenario	Definition	LOS/ NLOS	Mob. km/h	Frequ ency (GHz)	Note
B1	Typical urban micro-cell	LOS NLOS	0–70	2 - 6	
B5c	LOS stat. feeder, below- rooftop to street-level	LOS	0	2 - 6	Extended B1
C2	Typical urban macro-cell	LOS/N LOS	0–120	2 - 6	

Table 2-3: Propagation scenarios used in the performance assessment of WINNER CG Metropolitan Area.

3. WINNER system design solutions targeting Metropolitan Area deployments

3.1 Overview

This section presents the WINNER system design solutions targeting metropolitan area deployments of WINNER system. As some technical solutions do not depend on the specific system deployment, results relevant also for Metropolitan Area deployments can be found from the Wide Area and Local Area deliverables [WIN2D61310] and [WIN2D61312], respectively. Performance assessment results, validating the results shown in this sections, are presented in section 4.

The areas of system design solutions covered in this section include the following

- Section 3.2: spatio-temporal processing
    - Preferred multi-antenna transmission schemes for metropolitan area deployments .
- Section 3.3: network synchronization
    - A distributed, self-organizing method for synchronizing the radio access points for WINNER system deployments where the cell sizes are small, like in urban microcell deployments.
- Section 3.4: relaying
    - Radio resource management for relay enhanced cells in metropolitan area deployments of WINNER system
    - MIMO cooperative relaying for metropolitan area deployments
    - Multi-user scheduling for relay enhanced cells.
- Section 3.5: multi-mode handover
    - Handover between FDD and TDD modes of WINNER system concept
    - This topic is presented in this deliverable, as in the performance assessment assumption metropolitan area deployments are assumed to utilise TDD
- Section 3.6: interference mitigation in metropolitan area deployments.
    - Resource partitioning in metropolitan area deployments
- Section 3.7: spectrum technologies
    - WINNER spectrum scenarios
    - Spectrum functions, spectrum sharing and co-existence, and spectrum assignment

As the results presented in this section have been obtained in various phases of WINNER project, it should be noted that some of the results are not fully in-line with the final WINNER system concept, and system design choices, presented in [WIN2D61314]. These kinds of results are still presented here in order to provide as broad insight as possible on deploying the system in metropolitan areas, and to illuminate alternative solutions to those that were selected for the system concept. The items that are not fully aligned with the WINNER system concept are noted within the text.

3.2 Spatio-temporal processing

The spatio-temporal processing for the WINNER system is based on the generic transmitter structure introduced in [WIN1D27] and later refined in [WIN1D210] and [WIN2D341]. The generic transmitter, depicted in Figure 3-1, offers a lot of flexibility in terms of the modulation and generalised multi-carrier (GMC) processing as well as spatial processing. Several different spatial processing techniques can be realised by different configurations of the generic transmitter. These include per antenna rate control (PARC), linear dispersion codes (LDC), different linear precoding (LP) or beamforming solutions, as well as combinations thereof. For further details, the interested reader is referred to [WIN2D341].

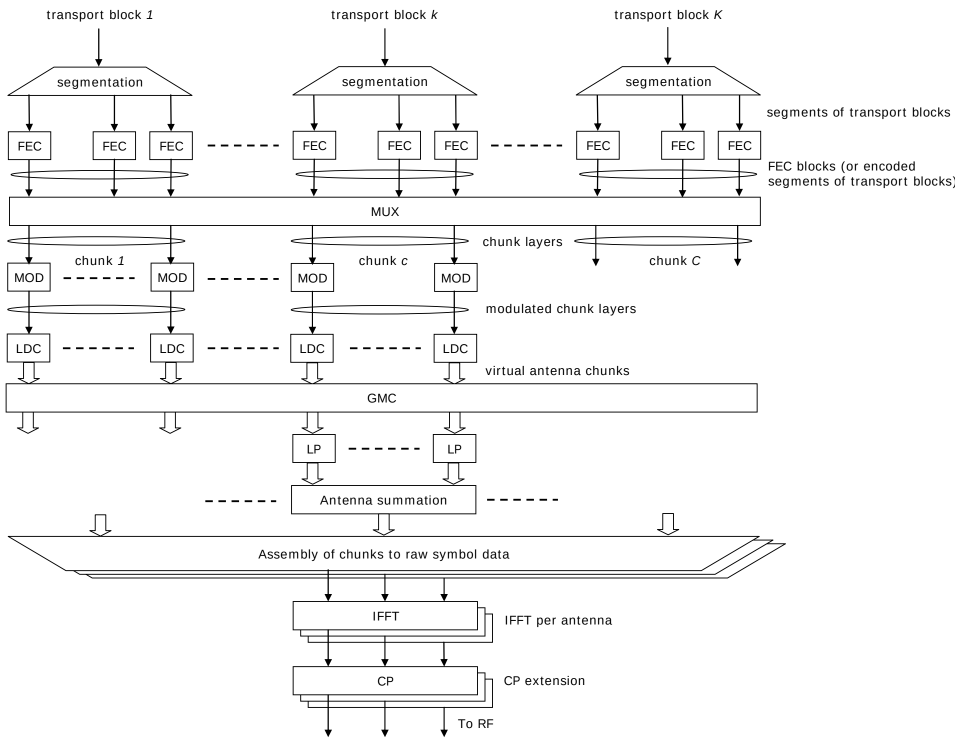

Figure 3-1: Generic transmitter for GMC.

3.2.1 Proposed configurations for Metropolitan Area deployments

Spatial processing schemes in the metropolitan area have to cope with the challenging radio propagation conditions, and must be able to meet the high throughput requirements. The narrow street canyons in the Manhattan grid deployment typically results in a high median SINR, which results in that the number of users benefiting from downlink multi-stream transmission, i.e. spatial multiplexing, is large. It can also be expected that sporadic bursts of strong interference will occur in the scenario; hence powerful interference rejection capabilities at both UTs and BSs are of major importance.

3.2.1.1 Downlink

Pedestrian mobility

For stationary or slowly moving users, e.g. sitting at a café with their laptop computers, it is proposed to use the same spatial-processing solutions as proposed for the local area scenario [WIN2D61312], i.e. multi-user MIMO precoding techniques, e.g. based on successive minimum mean square error (SMMSE) [SH04] or regularised block diagonalisation (RBD) [SH06]. Multi-user MIMO precoding exploits the channel state information (CSI) available at the transmitter in order to mitigate or completely eliminate the multi-user interference at the receiver. Due to the employed TDD mode and the low user mobility, instantaneous CSI in reasonable quality can be assumed to be available at the base station. This facilitates frequency-adaptive chunk-wise precoding which can be combined with spatial multiplexing to achieve very high data rates. Such a system benefits significantly from having multiple antennas at the base station since additional antennas enable more streams to be spatially multiplexed using the same time and frequency resources. However, in the metropolitan area scenario the number of antenna elements must be reasonably low in order to not require a too large and complicated antenna installation. It is proposed to have eight antenna elements, e.g. in the form of a four-element cross-polarised array. The number of transmitted spatial streams can then in theory also be eight, but in practise four has been found more feasible. Dual-antenna UTs are proposed, employing interference rejection combining (IRC), a.k.a. minimum mean square error (MMSE) or optimal combining [Win84], in order to combine the received signals and handle the possible remaining multi-user interference as well as inter-cell interference.

The system model of downlink multi-user MIMO precoding is shown in Figure 3-2. The base station is equipped with M_{T} antennas, each user terminal with $M_{\mathrm{R},k} = 2$ antennas. There are K users in total out of which K_{cc} are served simultaneously within one chunk via SDMA. Consequently, the total number of receiving antennas is equal to $M_{\mathrm{R}} = \sum_{k=1}^{K_{\mathrm{cc}}} M_{\mathrm{R},k} = 2 \cdot K$. Each user receives $r_k = 1$ data stream, the total number of data streams is therefore equal to $r = \sum_{k=1}^{K_{\mathrm{cc}}} r_k = K_{\mathrm{cc}}$.

The data model can be summarized as

$$\boldsymbol{y} = \boldsymbol{D} \cdot \left(\boldsymbol{H} \cdot \boldsymbol{F} \cdot \boldsymbol{x} + \boldsymbol{n} \right)$$

where $\boldsymbol{D} \in \mathbb{C}^{r \times M_{\mathrm{R}}}$ is a block-diagonal matrix containing the receive filters $\boldsymbol{D}_k \in \mathbb{C}^{r_k \times M_{\mathrm{R},k}}$, the matrix $\boldsymbol{H} \in \mathbb{C}^{M_{\mathrm{R}} \times M_{\mathrm{T}}}$ represents the MIMO channel matrix, $\boldsymbol{F} = [\boldsymbol{F}_1, \ldots, \boldsymbol{F}_K] \in \mathbb{C}^{M_{\mathrm{T}} \times r}$ denotes the overall precoding matrix and the vectors $\boldsymbol{x}$, $\boldsymbol{y}$ and $\boldsymbol{n}$ represent the vectors of sent symbols, received symbols and additive noise at the receive antennas, respectively.

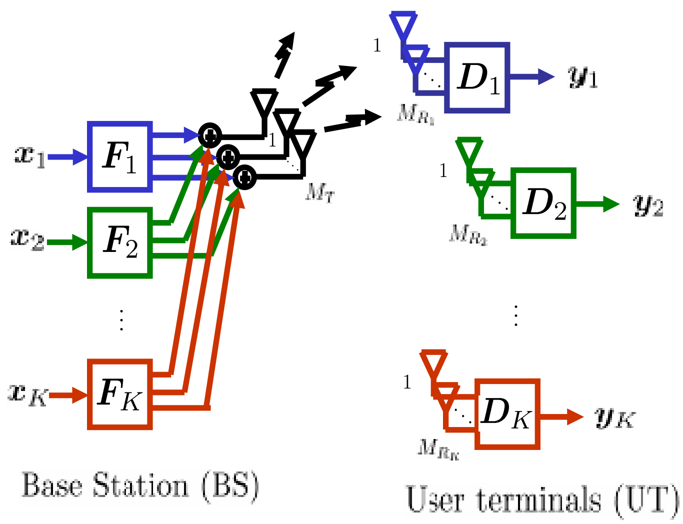

Figure 3-2: System model of downlink multi-user MIMO precoding.

We assume that the base station has acquired channel state information from K users through dedicated pilots in the users' uplink transmission. Note that in case the users were divided into competition bands, to reduce the pilot overhead, K refers to the number of users per competition band, i.e., all the users that compete for assignment of the resources of one chunk. It is the task of the scheduler to find a group of K_{cc} out of K users that is optimum in terms of a suitable criterion (such as maximum sum throughput under fairness constraints). One such scheduler is ProSched, see e.g. [WIN2D341] or Section 3.4.3 for details.

The task of the linear precoder is to compute the precoding matrices $\boldsymbol{F}_k \in \mathbb{C}^{M_T \times r_k}$ such that the multi-user interference is minimised while balancing it with noise enhancement. The linear precoding techniques SMMSE precoding [SH04] and RBD [SH06] are able to extract the full antenna diversity by successively optimising the users' subspaces. The main idea is to successively calculate the columns in the precoding matrix, each corresponding to one receive antenna, in order to reduce the performance loss due to cancellation of interference between two closely spaced antennas at the same terminal. With complete CSI available at the BS, the equivalent combined channel matrix of all users after the precoding is block diagonal for high SINRs. It is then possible to apply any other previously known single-user MIMO technique on each user's equivalent channel matrix. After the precoding, singular value decomposition (SVD) of each user's equivalent channel is performed. If we want to maximise the capacity of the system we use bit loading on the eigenmodes of all users. If we want to extract the maximum array gain, we transmit only on the dominant eigenmode of each user. Dominant eigenmode transmission can provide maximum SINR at the receiver and minimum BER performance. By using these algorithms the system performance is efficiently improved by eliminating inter-stream interference. More detailed descriptions can be found in [WIN2D341].

Vehicular mobility

As a significant fraction of the users in metropolitan areas are stationary or slowly moving (pedestrians or e.g. indoor users), multi-user MIMO precoding is the strong cornerstone of the preferable spatio-temporal processing solution. However, for higher terminal mobility, i.e. for users in cars and public transportation vehicles, the performance of multi-user MIMO precoding degrades. Better performance is obtained with e.g. the more robust adaptive linear dispersion codes (LDC) which adaptively can switch between spatial multiplexing and transmit diversity.

In order to keep the UT antenna configuration in line over the different concept group scenarios, a 2x2 LDC configuration is proposed, i.e. to utilise two transmit antennas at the BS and two receive antennas at the UT. Since the BS antenna configuration is proposed to be a four-element cross polarised array (see above), it is proposed to use one polarisation each of the outer elements per user in order to get the transmit antennas as uncorrelated as possible which is beneficial for LDC transmission. To obtain equal transmit power distribution to all antenna elements, different pairs of polarisation elements are used for different users.

As diversity mode, i.e. single stream transmission mode, it is proposed to use the well-known Alamouti scheme [Ala98], which has the following modulation matrix:

$$\mathbf{X}_{Ala}(s_1, s_2) = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \tag{1}$$

As spatial multiplexing mode, i.e. for dual-stream transmission, no particular mode is recommended, but the results given in Section 4.2.1 are obtained with the traditional V-BLAST scheme [Fos96].

Typically, the Alamouti scheme is preferred in the low SINR region, while the spatial multiplexing mode is superior for medium and high SINRs, and also for cases with low correlation. Hence, the adaptation between them is based on SINR, but also on a measure of the MIMO channel rank. The reason why it is needed is that in case of strong correlation or line of sight (which is rather common in the narrow street canyons in the metropolitan area scenario), the number of streams which the MIMO channel can support is reduced. Therefore, a channel quality indicator (CQI) reflecting the spatial structure condition of the channel is also important for LDC adaptation. A good measure is the relative condition number of the MIMO channel, given as:

$$\kappa_n = \frac{\lambda_n\left(\mathbf{H}^H \mathbf{H}\right)}{\lambda_{\max}\left(\mathbf{H}^H \mathbf{H}\right)}, \tag{2}$$

where we compare the nth smallest eigenvalue to the largest eigenvalue, assuming that the channel powers are normalised. For the two transmit antenna case we consider here, the first condition number κ_1 is used. These CQIs (condition number and received SINR) are computationally efficient since they are not required per stream.

In order to decide which LDC should be used by the BS at a certain instant, a two-dimensional look-up table for the thresholds of SINR and the condition number is constructed in advance. The look-up table indicate the preferred LDC if SINR and the condition number fall in specific intervals. The selection of schemes is according to optimisation of throughput, i.e. the scheme with the highest throughput is selected in this two-dimensional interval.

The adaptation and rank updating can be done at super-frame level, and a CQI in the form of SINR is required to be fed back from the UT. Due to the TDD mode, channel knowledge for calculation of channel rank (condition number) can be obtained from uplink transmissions utilising the reciprocity principle.

For receive processing at the UT, it is proposed to use IRC in order to be able to separate the received signals and suppress possible interference.

Adaptation mechanism

As can be understood from the recommendations above, the downlink reference design for metropolitan area deployments needs to include multiple spatio-temporal transmission schemes. Hence, an adaptation mechanism is needed in order to select the optimal scheme for each situation.

For low mobility users, say moving with a velocity up to 10 km/h, we want to apply multi-user MIMO precoding, whereas for higher mobility users we need the more robust LDCs. Hence, it is proposed that the adaptation mechanism measures/estimates the velocity/mobility of the user. Some options, on how this can be carried out, exist. One option could be to assume that the UTs are equipped with GPS receivers for positioning purposes, which then also can be used for velocity measurements and fed back to the BS. In the most simple case, this requires 1 bit to be transmitted, i.e. telling whether multi-user MIMO precoding should be applied or not. However, we cannot take for granted that UTs are equipped with GPS receivers. Another option is to estimate the velocity or Doppler frequency based on the channel estimation process. In the TDD mode we can utilise the reciprocity principle and let the BS estimate the maximum Doppler frequency f_D or velocity v of the user based on the uplink channel. In fact, f_D is proportional to the user velocity [Lee97] and given by:

$$f_D = \frac{v}{\lambda} = \frac{vc}{f}, \tag{3}$$

where λ is the wavelength, c the speed of the light and f the transmission frequency.

Based on the synchronisation process the BS will be able to notice a change in the Doppler frequency. Let us assume t_0, the time instant of the synchronisation. By comparing the current channel estimate with previous estimates, the BS can estimate the coherence time T_c of the radio channel. This could for example be carried out by constantly comparing the auto-correlation functions of the channel estimate $\hat{h}(t_0)$:

$$T_c = \arg_{\Delta>0}\left(\left|R_{\hat{h}}(t_0,t_0) - R_{\hat{h}}(t_s,t_s+\Delta)\right| \geq \beta\right), \tag{4}$$

where $R_x(t_1,t_2)$ is the auto-correlation of the random variable x and equal to $E\left[x(t_1)x^*(t_2)\right]$. Δ is a time interval greater than zero. β is close to one and can be chosen according to the desired accuracy (e.g. granularity) of the estimated coherence time.

The estimated coherence time can then be used to calculate the Doppler frequency according to [Rap02]:

$$f_D = \frac{1}{T_c}\sqrt{\frac{9}{17\pi}} \tag{5}$$

Finally, (3) is used to calculate the user velocity.

The adaptation mechanism then takes the estimate/measurement and uses it for selection of spatial transmission scheme. If the user velocity is below a certain desired velocity threshold Γ (e.g. 10 km/h), a multi-user (MU) MIMO precoding scheme (e.g. SMMSE) is applied. Otherwise the more robust LDC scheme is applied. This procedure is then performed as a first stage in the spatial adaptation mechanism. In case the user terminal mobility estimation indicates that LDC is the preferred scheme, a second stage is applied where SINR and channel rank is considered in order to select the specific LDC, as described above.

3.2.1.2 Uplink

For the uplink, it has been concluded that receive diversity at the base station with maximum ratio combining (MRC) brings significant gains for both cell throughput and cell edge user throughput. Furthermore, interference rejection combining (IRC) instead of MRC improves the performance even further, due to the possibility for strong uplink interference in the narrow street canyons. The transmit diversity gain of the Alamouti baseline scheme [Ala98] is basically invisible for cell edge users although it still brings small improvement for median and high SINR users (see Section 4.2.2). Hence, the value of uplink Alamouti transmission can be questioned, especially when considering the cost of the extra radio transmitter chain it requires.

Consequently, from a pure performance point of view, the recommendation for uplink is to use single antenna transmission and multi-antenna reception with IRC receiver processing. However, the downlink multi-user MIMO precoding requires dedicated pilot transmissions per antenna in the uplink for acquiring the CSI, and thus uplink transmissions from both UT antennas are needed. A solution which achieves this but still only requires one radio transmitter chain is antenna hopping, i.e. the radio transmitter chain switches between the two antennas every frame. This means that CSI for each antenna is only obtained every second frame, but due to the low mobility in the case when multi-user MIMO precoding is used the CSI does not change too rapidly. Antenna hopping also provides some diversity gain, given the low mobility. For higher velocities, e.g. at those where adaptive LDCs are used on the downlink, this diversity gain is more or less gone as is the pilot per antenna requirement, hence the UT preferably then only transmits from one antenna. When it comes to the number of receive antennas at the BS, we have eight available if we follow the downlink recommendation to use an array with four cross-polarised elements. In order to acquire CSI for the downlink multi-user MIMO precoding, channel estimates have to be obtained for all eight antennas, however, it is a trade-off between performance and complexity whether all these eight really should be used in the IRC processing. Based on the results in Section 4.2.2, the recommendation is to use at least four receive branches, since that is required to meet the WINNER spectral efficiency requirements [WIN2D6114]. This is also in line with the proposal for the wide area scenario [WIN2D61310].

The IRC processing can also preferably be used as basis for uplink SDMA as proposed for the wide area scenario [WIN2D61310], i.e. several users can simultaneously be scheduled for transmission on the same time-frequency resources. This will introduce intra-cell multiple access interference in the system, but the multi-antenna receiver with IRC processing at the BS is used to separate the users. In addition, successive interference cancellation (SIC) after channel decoding can be used as performance enhancing technique to further limit the impact of the intra-cell interference introduced by SDMA. Results on this illustrating significant system performance gains are given for the wide area scenario in [WIN2D61310], and it can be expected that similar gains can be achieved also in the metropolitan area scenario.

3.3 Network Synchronisation

Network synchronisation is defined as aligning all internal time references within the network, so that all nodes agree on the start and end of a super-frame. To do so in a self-organised manner, similar rules to the ones used in nature by fireflies are applied: each node maintains a time reference, referred to as the phase function, which is updated upon reception of a pulse from other nodes. The update rule is extremely important, and it was shown by Mirollo and Strogatz in their seminal paper [MS90] that the phase increment, which is a function of the internal phase, needs to be always strictly positive.

In this section, we first review the super-frame preamble structure that is currently defined and used for synchronisation. In Section 3.3.2.1 a self-organised network synchronisation scheme derived from the firefly synchronisation principle is extended to fit into the super-frame preamble. Thanks to the coarse misalignment mode, cells that are initially completely misaligned are always able to synchronise. However, in the metropolitan area scenario, the time to synchrony increases drastically with the size of the considered Manhattan grid. To prevent instabilities and accelerate the time to synchrony, reference nodes that have access to a global timing reference, through the Global Positioning System (GPS) for example, should be present in the network. The behaviour of these nodes with regards to normal nodes is detailed in Section 3.3.2.2.

3.3.1 Preamble Structure and Constraints

Within the first phase of the WINNER project, network synchronisation was integrated into the system. The most noticeable contribution is the inclusion of two synchronisation words within the preamble of the WINNER super-frame.

The super-frame preamble of the WINNER system consists of five consecutive time slots:

- “UL Synch” of duration $T_{\mathrm{UL,Synch}}$: transmission slot for the synchronisation word transmitted by UTs.
- “RAC” of duration T_{RAC}: Random Access Channel.
- “GI” of duration T_{GI}: Guard Interval.
- “DL Synch” of duration $T_{\mathrm{DL,Synch}}$: transmission slot for the synchronisation word transmitted by BSs.
- “BCH” of duration T_{BCH}: Broadcast Channel used by BSs to transfer general information to members of the cell.

The whole duration of these time slots corresponds to the length of the preamble T_{preamble}. The super-frame preamble is shown in more detail in Figure 3-3.

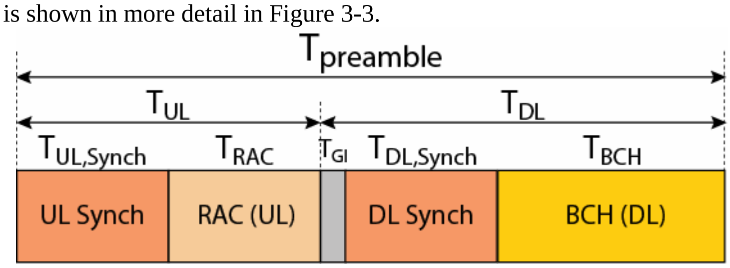

Figure 3-3: WINNER Super-frame Preamble.

The network synchronisation procedure uses the two synchronisation words as follows. The first sync word, labelled “UL Synch”, is used by UTs to transmit a synchronisation word that is received by BSs to adjust their internal clock and synchronise. In a similar fashion, the second sync word, labelled “DL Synch”, is used by BSs to broadcast a synchronisation word that is used by UTs to synchronise. The necessity for having two distinct transmission slots is justified by the fact that nodes cannot receive and transmit simultaneously. Hence one group relies on the other to synchronise.

To reproduce behaviour based on pulses such as in the Mirollo and Strogatz scheme, the network synchronisation unit is placed close to the link synchronisation unit. The link synchronisation unit uses the UL and DL synchronisation words to estimate the start of a super-frame. This information is used by the network synchronisation unit to know when a node started transmission.

3.3.2 Synchronisation Rules and Process

Initially when a UT accesses the network, it needs to synchronise with its base station by following its timing reference, so that it does not disturb ongoing transmissions. This Master-Slave type of synchronisation is fine for intra-cell synchronisation, and is currently deployed in GSM and UMTS networks.

The problem of inter-cell synchronisation consists of aligning the timing reference of all base stations. As direct communication among base stations is not always available in the WINNER concept and cooperation for network synchronisation among all network operators is not mandatory [WIN1D71], a self-organised synchronisation process that relies on UTs and BSs is presented.

3.3.2.1 Coarse Misalignment

Given the super-frame structure, two groups need to form: one formed by BSs and the other by UTs. To enforce this formation, the phase function of BSs is adjusted when detecting a transmission from UTs, and vice versa. Hence two distinct synchronisation sequences "UL Synch" and "DL Synch" are used. Figure 3-4 shows the two state machines defined for BSs and UTs as well as the super-frame preamble structure, when nodes are synchronised.

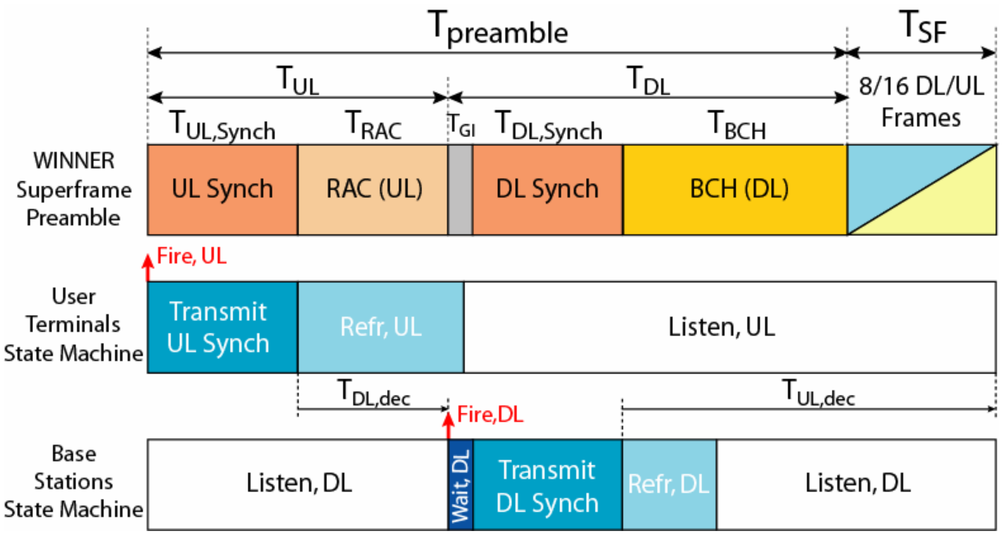

Figure 3-4: State Machines of Network Synchronisation units for coarse misalignments.

Based on the two state machines of Figure 3-4, interactions occur between the two groups (BSs and UTs) when a node transmits and nodes from the other group detect this transmission. Detection of the distinct synchronisation words is done by the link level synchronisation procedures. This allows for robust detection and avoids too much additional processing at the receiver.

Key to separating nodes into two predefined groups is done in two parts:

- Coupling at Base Stations: if at instant τ_j, a BS node *i* is in 'Listen' state, where its phase function ϕ_i linearly increments over time, and a UT node *j*, which can communicate with *i*, started transmitting $T_{\mathrm{UL,Synch}} + T_{\mathrm{DL,dec}}$ before, then the receiving BS node *i* increments its current phase ϕ_i:

$$\phi_i(\tau_j) \rightarrow \phi_i(\tau_j) + \Delta\phi_{\mathrm{BS}}(\phi_i(\tau_j)) \text{ where } \phi + \Delta\phi_{\mathrm{BS}}(\phi) = \alpha_{\mathrm{BS}} \cdot \phi + \beta_{\mathrm{BS}}$$

- Coupling at User Terminals: if at instant τ_i, a UT node *j* is in 'Listen' state, where its phase function ϕ_j linearly increments over time, and a BS node *i*, which can communicate with *j*, started transmitting $T_{\mathrm{DL,Synch}} + T_{\mathrm{UL,dec}}$ before, then the receiving UT node *j* increments its current phase ϕ_j:

$$\phi_j(\tau_i) \rightarrow \phi_j(\tau_i) + \Delta\phi_{\mathrm{UT}}(\phi_j(\tau_i)) \text{ where } \phi + \Delta\phi_{\mathrm{UT}}(\phi) = \alpha_{\mathrm{UT}} \cdot \phi + \beta_{\mathrm{UT}}$$

Thanks to this strategy, the formation of two groups is controlled: starting from a random initial state, where all nodes fire randomly, after following the simple coupling rules, UTs and BSs separate over time into two groups, all BSs firing T_{UL} after UTs and all UTs firing T_{DL} after BSs. This state corresponds to a synchronised state. Simulation results for this synchronisation strategy in the considered metropolitan area deployment are presented in Section 4.3.

3.3.2.2 Imposing a Global Reference to Self-Organised Synchronisation

Performing slot synchronisation in a self-organised manner presents a number of advantages such as the robustness against failure of the base station and the adaptation to the network topology.

In a cellular network, an issue with employing such a self-organised synchronisation algorithm is *scalability*. In very large networks, it has been shown that synchronisation can fall apart due to loops in the network, and a synchronised state is never reached.

To prevent this problem, which is likely to occur in WA and MA scenarios, a reference needs to be imposed onto the network. To do so, a few nodes within the network need to have access to a Primary Reference Clock, which is available through the Global Positioning System (GPS), and should redistribute this timing reference. Furthermore imposing the stable reference given by GPS helps avoiding stability issues that are common to oscillators.

Hence, we consider a scenario where only a few nodes have access to an absolute clock reference. The objective is to let these reference nodes impose a global time reference to the entire network.

As only a few nodes are considered to have access to a global reference, these reference nodes need to enforce their timing onto normal nodes. A reference node corresponds to an oscillator that periodically transmits the “DL Sync” word at the start of every super-frame without ever modifying its phase. This deafness is problematic if reference and normal nodes run at the same frequency, and results in normal nodes not being able to follow the timing of reference nodes [TA07].

To counter this undesired effect, reference nodes run at a different frequency. As noted above, this frequency should be higher than the frequency of normal nodes. Thus the super-frame duration of reference nodes needs to be shorter. Means of achieving this is to shorten the duration of the “Wait,DL” state, which is equal to T_{GI}, the guard interval duration, for normal nodes. So for reference base stations, the guard interval is shortened, so that $T_{\text{Wait,ref}} < T_{GI}$. Doing so can be done within the system concept without incidence, as $T_{\text{Wait,ref}}$ is reduced only by a fraction of the guard interval duration.

The state machine of reference base stations is shown in Figure 3-5 along with the super-frame structure (top) and the state machine of normal base stations (middle).

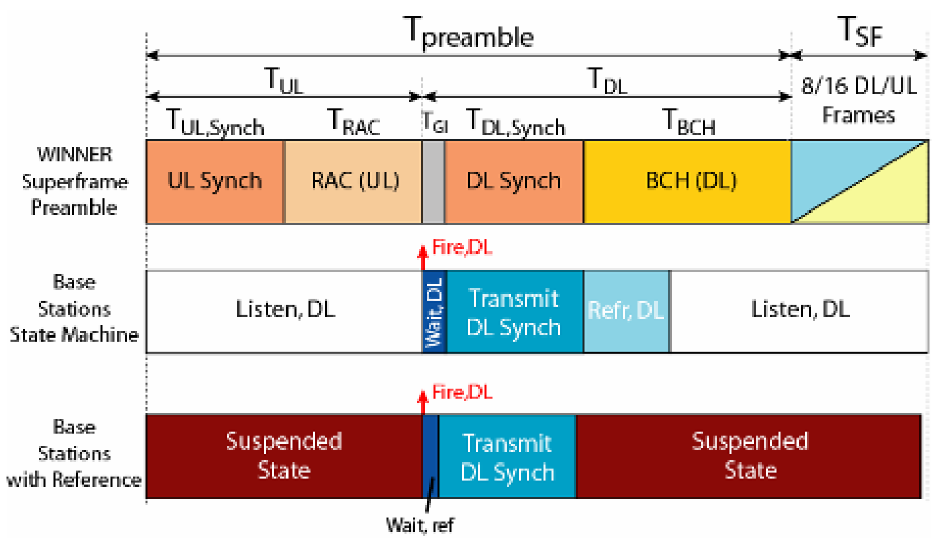

Figure 3-5: State Machines of Reference Base Stations.

The exact duration of $T_{\text{Wait,ref}}$ is determined by the accuracy of slot oscillators: reference oscillators need to run faster than any normal nodes, so that their timing is always imposed.

3.4 Relaying

It is foreseen that new spectrum in different frequency bands will be allocated for future radio communication systems. The main part of these (IMT) candidate bands are beyond 3 GHz. The high carrier frequencies of these bands together with regulatory constraints on the transmission power will limit the range for broadband services. Relay based deployments is a promising technology to save costs while achieving a similar service level or coverage than a base station only deployment.

Relaying technologies have been studied in WINNER since the very beginning of the project with the purpose of providing an efficient relaying concept able to guarantee the envisaged broadband radio coverage under the assumption of cost efficiency. Although the common effort was made to design a consistent solution, the work was structured accordingly in order to cover the requirements of all three concept groups: wide area, metropolitan area and local area. Thanks to this approach a significant dose of flexibility was introduced to the resulting relaying concept such as the support for: single path and cooperative relaying, MIMO relaying and cooperating RAPs selection. In the following we present aspects of the relaying concept that are relevant to the metropolitan area concept group scenario.

As indicated by the simulation results in [WIN2D353], a proper radio resource management is essential to utilize the potential benefits of relay based deployments. Three types of links share the radio resources in a REC, BS-UT, RN-UT and BS-RN. If cooperative relaying is used in the REC, two additional link types have to be considered (BS, RN) – UT and (RN, RN) – UT. WINNER focuses on ubiquitous radio access comprising different scenarios. Thus a flexible radio resource management solution has been presented in [WIN2D353] that can be applied to the MA CG scenario. The radio resource management is tightly coupled with the inter-cell interference coordination techniques described in section 3.6 and the spatio-temporal processing solutions described in section 3.2. Section 3.4.1 illustrates the RRM solution for the MA CG scenario. Further, cooperative relaying has shown significant gains especially in the MA CG scenario and we present the cooperative relaying solution for the MA CG scenario in section 3.4.2. Finally, section 3.4.3 presents a centralised multi-user scheduling scheme for relay enhanced cells.

3.4.1 RRM for relay enhanced cells in the MA CG scenario

The WINNER relaying concept assumes a "distributed" MAC [WIN2D351], i.e., the BS partitions the resources between itself and the RNs in the REC. The RNs can freely allocate these resources and thus frequency adaptive transmissions and multi-antenna schemes for UTs served by RNs can be supported without forwarding all the required control signalling to the BS. Secondly, the complexity of the BS is reduced.

[WIN2D352] introduces the RRM framework for RECs based on flexible resource partitioning, i.e. the subdivision of the overall system resources for autonomous scheduling at individual RAPs. Figure 3-6 illustrates the resource partitioning framework and the corresponding timescales in the WINNER system. The resource partitioning for RECs has to work on a faster timescale than the inter-RAN load balancing (several seconds) and the short-term spectrum assignment (500ms-1s). It operates mainly on the same time-scale than the inter-cell resource partitioning (100ms). In this case RNs can be treated similar than BSs in the inter-cell resource partitioning. Additionally, a fast intra-REC resource partitioning, every superframe (~6ms), is supported.

In the MA CG scenario we propose a centralized resource partitioning within the REC, i.e. the BS partitions the resources for itself and the RNs in the REC. The BS receives resource requests and measurement reports from the RN. Based on the received information the BS decides the new resource partitioning and sends it to the RNs within its REC.

The signalling is routed through an own RLC instance to ensure a reliable data transfer. The resource partitioning messages have to be forwarded to all the RNs in the REC before the new resource partitioning is active. To allow sufficient time for at least one retransmission, the message has to be sent at least 2 frames in advance for a two hop deployment. For deployment scenarios with more than 2 hops, the additional delays for each hop will restrict the update frequency of the resource partitioning and a fast resource partitioning every superframe might not be feasible. Further, to ensure stability we propose an update only every 100ms.

The resource partitioning strategy and the content of the resource partitioning message will depend on the deployment and the utilised technology options, e.g. the spatial temporal processing solutions used at the RNs or what forms of interference mitigation techniques the UTs are capable of. Soft frequency reuse has been identified as a potential interference coordination scheme for wireless networks [WIN2D471], [WIN2D472], which is suitable to the MA CG scenario. The concept of soft frequency reuse was presented in the context of RECs in [WIN2D351]. Instead of frequency reuse, power masks in the time or frequency domain are assigned to each RAP. Thus, soft resource partitioning enables frequency reuse one and at the same time each RAP has high power resources with reduced interference available to schedule UTs in the border area with other RAPs. Table 3-1 includes the essential information about the soft frequency reuse resource partitioning scheme. The power mask levels can be adjusted between 0 and 1 depending on the interference and load situation in the network.

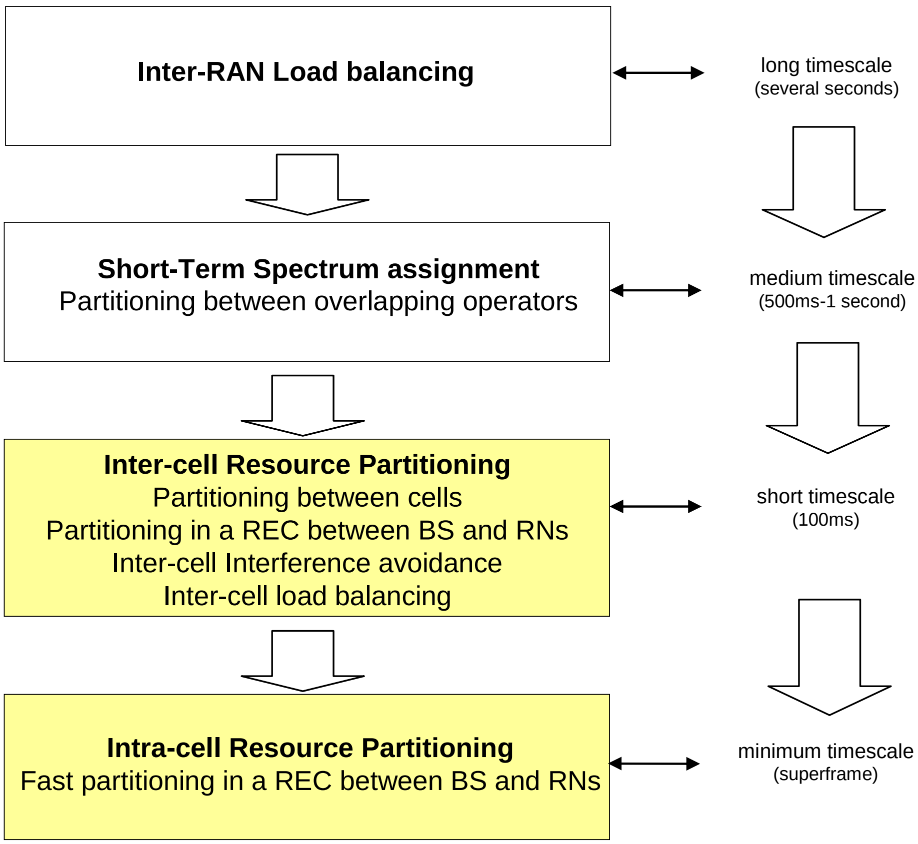

Figure 3-6: Resource Partitioning framework and corresponding timescales in the WINNER system.

Without a proper scheduling algorithm, the potential benefits of soft frequency reuse cannot be exploited. Therefore, we present the phased scheduler, a new scheduling algorithm for soft frequency reuse. It aims to increase the throughput of low throughput users while keeping an at least similar cell throughput than the proportional fair scheduling algorithm. The scheduling algorithm exploits SINR information for the different power mask areas. It uses this information to schedule the lowest SINR users in power mask areas where they have their highest SINR. A detailed description of the scheduling algorithm can be found in [WIN2D352].

Resources to be partitioned	Power levels for each group of chunks in the frequency domain + Frames in time domain where RAP is allowed to transmit
Granularity of resources	Groups of 30 chunks
Measurements/Information related	
Measurements required	Received signal strength from neighbouring RAP relative to serving RAP
Who performs the measurements	UT
Granularity of measurements	2dB
Additional information	Required resources (in chunks) to serve UT
How often	New measurement and message every 100ms
Who collects it	Serving RAP

Who uses it	BS (serving RAP in static power mask case)
Information push or poll	Push
Resource partitioning message	
Content	New power mask
Who generates it	BS
Who consumes it	RNs
What timing constraints	New partitioning at most every 100ms

Table 3-1: Essential information about soft-reuse scheme.

3.4.2 MIMO cooperative relaying

Cooperative relaying has been identified as a suitable technology to improve the user throughput in the MA CG scenario. For cooperative relaying it is necessary to coordinate the transmissions of several RAPs. The cooperative relaying concept presented in [WIN2D352] suggests that the BS performs the resource allocation for cooperatively served UTs in the same way as for UTs served by the BS.

Figure 3-7 illustrates the resulting task for the BS. Next to sending resource partitioning messages to the RNs it also sends the resource allocation for the cooperatively served UTs for the next frame. An efficient signalling scheme is developed in WINNER to signal the resource allocation to the UTs. The same number of bits will be required to signal the resource allocation for cooperatively served UTs to the cooperating RN(s). However, as the link quality of the BS-RN link will be much higher than the average link quality to the UTs located in the cell, it will require much less resources. Therefore the signalling load will not be a problem. One of the cooperating RAPs is the main serving RAP of the UT and it broadcasts the allocation table to the UT. The main serving RAP is also responsible for HARQ retransmissions.

One of the big challenges in the design of an OFDMA system with frequency adaptive scheduling is to keep the signalling load low, while still capturing most of the potential scheduling gain. In the case of cooperative relaying this is even more crucial because if a RN is the main serving RAP, all the feedback signalling has to be forwarded by the RN to the BS. The resulting additional delay will restrict the applicability of frequency adaptive scheduling and it will probably only be beneficial for lower speed UTs compared to the non-cooperative case. However, as the UT speed is assumed to be low in the MA CG scenario, these should not significantly degrade the system performance.

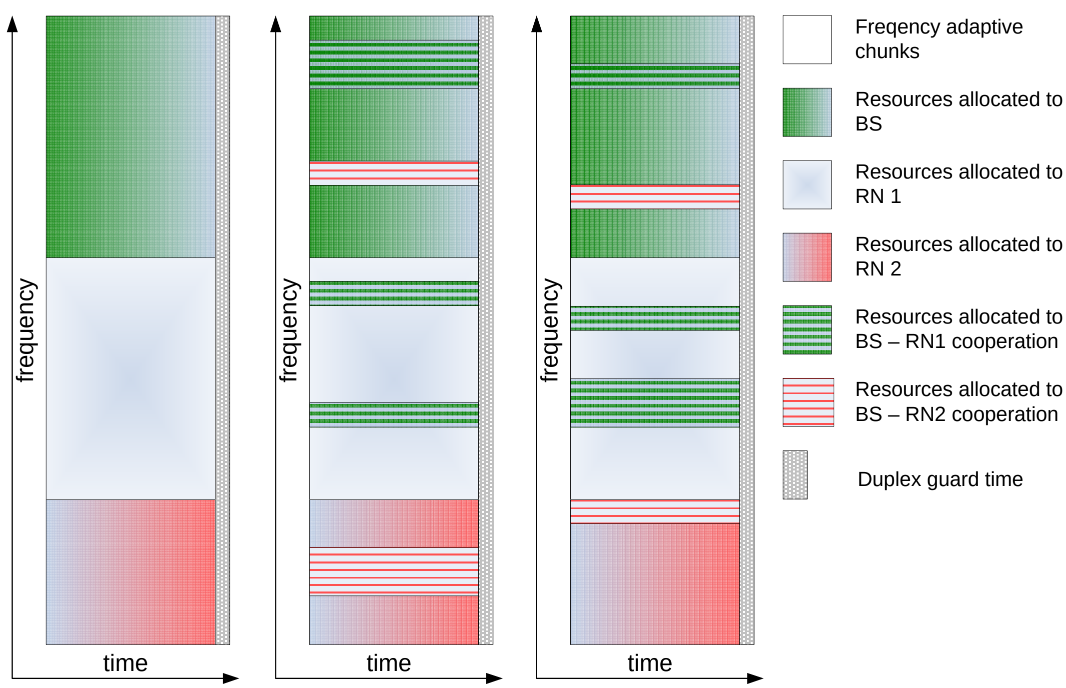

Figure 3-7: BS performs resource partitioning (left) and allocates resources for cooperative transmissions in each frame (middle and right).

Two-hop relaying protocols are divided into two phases: in the first phase the BS transmits data to the RN and in the second phase the RN forwards this data. To gain on large-scale spatial diversity, most cooperative relaying protocols further benefit from a combination of the first phase and second phase transmissions. In a multiple-antenna based system this implies that dedicated MIMO algorithms cannot be applied (for instance beamforming and other SDMA algorithms), since *one* stream is only optimised to *one* destination. Furthermore, as the position of a RN can be well chosen to obtain good channel conditions, the data rate on the relay link is likely to exceed the data rate on the RN-UT links. This inhibits cooperation on physical layer because both links use different modulations as well as information combining and the UT would be unable to decode the BS transmission. One solution might be to decrease the data rate on the relay link and to forbear from using MIMO algorithms, which could lead to significant performance degradation. Thus, we propose a cooperative relaying scheme that does not rely on the combination of first and second hop transmissions.

Secondly, the cooperative relaying scheme should be compatible with the spatial temporal processing schemes utilised in the MA CG scenario. Therefore, we propose to use distributed MU-MIMO based on the linear precoding techniques SMMSE or RBD, as suggested in section 3.2.1.1, to serve slowly moving UTs cooperatively. Similarly, as proposed in section 3.2.1.1, the cooperating RAP should use the more robust adaptive linear dispersion codes (LDC) which adaptively can switch between spatial multiplexing and transmit diversity for faster moving UT.

3.4.3 A low-complexity centralised multi-user scheduling approach for REC with coordination

In a relay enhanced system with the option of using MU-MIMO precoding at the transmitting stations, an algorithm is needed to decide which users should be served simultaneously by the MU-MIMO scheme in each chunk. While doing so, inter-cell interference can be mitigated as well, depending on the amount of coordination available between the transmitters. As a simplification, as the RNs are stationary, this can be exploited in the MU-MIMO scheme during the scheduling process as presented in [WIN2D341] Annex G.1.

A multi-user spatial scheduling concept for MU-MIMO based relay enhanced systems has been developed in WINNER. The development is based on the low complexity scheduling algorithm ProSched [FuDeHa05b] and its extension to interference avoidance scheduling for multiple co-operating base stations [FuDeHa06]. The ProSched approach inherently allows the consideration of both spatial correlation and optimal group size. It consists of two parts:

1. We use a scheduling metric which reflects the performance of one user's effective channel after any MIMO transmit precoding in the presence of a set of other users that are to be served simultaneously. The metric is an estimate of the Shannon rate with Zero Forcing precoding which can be considered an upper bound for other linear precoders. It has the following advantageous properties:
   - The ZF capacity of one user can be written with the help of an orthogonal projection into the intersection of the nullspaces of all other users' channels in the same group. The projection would normally have to be recomputed for every user in every possible combination. Instead, ProSched approximates the intersection by a product of projection matrices into the nullspaces of the single users. These matrices remain constant throughout the scheduling run, which dramatically reduces complexity. This means that the precoding matrices do not have to be computed while testing combinations. For details see also [WIN2D341].
   - Capacity as a metric reflects the impairment of spatial correlation and the effect of the average power assigned to a user, which again reflects the SDMA group size. It can be calculated based on channel matrix knowledge as well as on second order statistics channel knowledge.
   - A capacity based metric can be combined with proportional fairness in the sense of [Ho01] and with methods taking into account fairness and QoS in the form of user rate requirements such as in [SveWiOt04].
2. A tree-based best candidate search algorithm is carried out to reduce the number of combinations to be tested. It delivers beneficial user terminal combinations for all possible group sizes and allows in a second step a decision on the best group size based on the scheduling metric. Joint scheduling of all chunks is possible as well as tracking of the solution in time.

3.4.3.1 ProSched for multiple co-operating BSs

The multi-BS extension presented in [FuDeHa06] consists of two modifications. The first one is to extend the per-user scheduling metric by an estimate of the total received intra-cell interference power at each terminal. This estimate is obtained using the already available orthogonal projection matrices and requires only matrix multiplications and no additional matrix decompositions.

The second part of the multi-BS extension is a virtual user concept (see also [WIN2D341]). The tree based search algorithm is no longer executed on user numbers, but on numbers representing all allowable combinations of users and transmitters (denoted, in the example below as user#@basestation#). In this way, the underlying algorithm stays the same except for the interference term that is to be taken into account when virtual users belonging to the same transmitter are grouped. The approach allows for hard and soft handover scheduling with the difference that in the case of hard handover, a virtual user is deleted from the tree once it has been assigned to a candidate group. In the case of soft handover, multiple transmitters may serve the same user with the help of another dimension such as orthogonal codes, which has to be taken into account in the metric by a division. Examples for soft and hard handover are given in Figure 3-8 for the case of two BS and 3 users. The identified candidate groups are displayed in yellow. In the last step of the algorithm a selection between them is made. To that extend, soft and hard handover are system designer's choices whereas extension of the algorithm can be thought of to provide an automated choice.

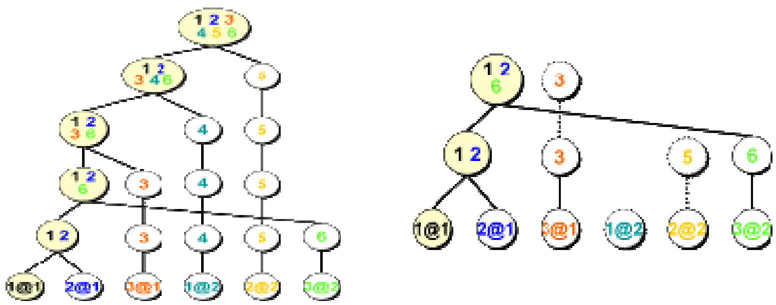

Figure 3-8: Example scheduling runs for soft and hard handover.

3.4.3.2 Extension to REC with coordination

Based on the version for multiple base stations, the spatially beneficial transmitter/receiver combinations can also be estimated in a REC. When the RNs are half duplex, they can be treated as user terminals in the time slots when the RNs receive. And when they transmit, they become additional base stations for the algorithm. Full duplex relay nodes could be supported in a similar fashion.

A key element of the extension is a model of a buffer at the RNs: RNs can only transmit as much as they have received before. Each RN's buffer is implemented as one number that contains the sum of the data of all UT rather than storing a vector for each user.

To generate the buffer levels for each UT needed in the scheduling metric we proceed in the following manner. When a RN is scheduled to receive, its currently achievable rate is added to its buffer. When a RN is scheduled for transmission, it is assumed that the buffer for transmission to each UT has been loaded optimally based on the achievable rates of the attached users in the current time slot (since we target maximum sum rate rather than user specific quality of service constraints). In real systems, this knowledge is of course not available a priori and represents a simplification which is justified because the channel changes only gradually. In other words, the situation in the time slot in which the buffers would have been filled can be assumed to be similar to the situation when transmission takes place. To generate the user specific buffer levels out of the single value buffer of a RN, the RN buffer figure is distributed via a standard water pouring algorithm on the UTs. To do so, the UTs' achievable rates when served from a certain transmitter represent the squared coefficients of the channels to be loaded and the RN buffer number is the power to be distributed.

To summarize, the benefit of ProSched is that during any testing of user assignments, the precoding solutions at each base station do not have to be re-computed but can be estimated with the help of fixed orthogonal projection matrices. The same applies to the interference which is different for each possible user assignment – it can also be estimated without knowing the final precoding solution. Additionally, ProSched may work with rank one approximation of the users' long term channels, reducing the required overhead dramatically.

3.5 Multi-mode Handover in Relay-Enhanced Cells

One key objective of the WINNER project is to develop an air interface which is adaptable to a wide range of different communication environments. The test environments utilized in WINNER project are Wide area, Metropolitan area and Local area, which are also referred to as Base Coverage Urban, Microcellular and Indoor test scenarios in [WIN2D6137], respectively. The desired flexibility can either be reached by parameterisation or even by different medium access algorithms. In order to be able to adapt to the different scenarios the WINNER system must be able to support different so called modes which are tailored to the current communication environment. The modes which are investigated in the scope of WINNER are the duplex schemes TDD, FDD and optionally half-duplex FDD. FDD is used in the base coverage urban test scenario whereas in the other two scenarios TDD is applied, each with different parameterisation [see WIN2D6137].

For the realisation of such a multi-mode capable system it is essential that the MAC protocol is multi-mode capable. It has to be able to offer functionalities to handle the different modes, i.e. mode detection, selection and switching. Furthermore taking into account the multi-hop, i.e. relay integration into the MAC protocol in the following it is shown that a multi-mode MAC protocol is feasible. In various deployment scenarios throughput, delay and durations of multi-mode handovers are investigated by means of simulations. Since the purpose of the investigations is the proof of the multi-mode concept, intra-mode handover aspects are not addressed. They are investigated in [WIN2D482] and [WIN2D483].

3.5.1 Structure of the multi-mode MAC protocol

The structure of the implemented Multi-mode MAC protocol is depicted in Figure 3-9. It consists of the lower two layers of the ISI/OSI reference model, namely the physical layer and the data link layer which is divided into the sub-layers RLC and MAC. In the physical layer the SINR values which are calculated on the basis of the transmissions requested by the MAC layer taking into account the pathloss and shadowing between transmitter and receiver, and the mobility of UTs. The calculated SINR is then mapped to the MI and afterwards to the PER using external mapping tables.

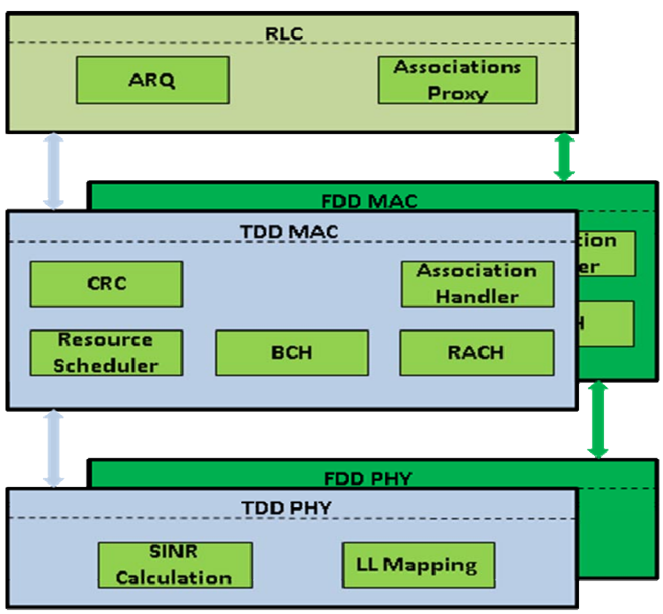

Figure 3-9: Structure of ISO/OSI layers 1 and 2 in the implementation.

The MAC layer contains two modes. These are the before mentioned duplex schemes TDD and FDD. They are modelled by considering the chronological build-up of the super-frame and frame phases respectively. All cells are fully synchronised in time. Each mode has its own resource scheduler, RACH and BCH phase, since it is assumed that TDD and FDD work in totally different frequency bands. Furthermore, each mode has its own so-called association handler, in order to be able to be connected via different modes independently. The association procedure will be outlined in more detail in the next section. Finally the RLC sub-layer consists of an End-to-End ARQ, i.e. from the BS to the UT. So, a possible RN is not involved in the ARQ. The purpose of the association proxy in the RLC is to have an instance that has an overview about all available modes, so that it is possible to decide which of the available modes to choose.

3.5.2 Association procedure

In principle the association procedure works as follows. During the preamble phase of the super-frame [WIN2D6137] the UT tries to detect the cell information sent by each RAP in the BCH. It is assumed that the BCH of neighbouring RAPs is sent on different subcarriers, so that it is possible to detect several RAPs at the same time. The UT collects the information about all detected BCHs above a certain threshold and evaluates them periodically concerning their signal quality. After that it starts an association process with the one that has the highest signal quality. The signalling for the association procedure during an exemplary inter-cell handover from a RN to another RN is depicted in the Figure 3-10.[1]

Initially, the UT is associated to the source RN. After detecting the BCH of the target RN with a higher signal quality than the one of the source RN, a decision is taken to request a handover to the newly detected RAP. In the following, the handover will be assumed to be initiated by the UT, whereas the decision to allow the handover is taken by the network. The UT sends a disassociation_req including the address of the new RAP to the source RN that is forwarded to the BS and afterwards to the GW, if the network decides to grant the handover. Thus, the GW is notified that packets in the DL coming from the backbone, e.g. the internet, are not to be sent to the source BS. The BS confirms the disassociation by sending a disassociation_grant to the source RN that forwards it to the UT. The disassociation signalling is treated like user data meaning that there are no dedicated resources allocated for it. Dropped or not detectable packets are caught by timeouts.

After the disassociation is completed, the UT sends an association_req to the target RN via the RACH, whose purpose is to provide uplink initial access requests. The target RN forwards the request to its BS and the new BS informs the GW about the update. Thereafter, the GW can forward DL packets to the correct BS. The BS confirms the successful association by sending an association_grant to the target RN and the RN forwards it to the UT. For the association_grant message to the UT, a broadcast transmission must be used. In the association signalling diagram above and in the simulations, it is assumed that transmission resources within the BCH timeslot in the super-frame preamble are used for this purpose.

Finally after receiving the association_grant the UT sends an association_completed message to the new BS via the new RN. The BS is allowed to send user data in the DL when it has received the association_completed message. The purpose of this “three-way-handshake” is to avoid sending user data in the DL too early. (If the association_completed message were not used, it would be possible that user data arrives at the UT before the association_grant, i.e. before the UT knows the association procedure was successful. The reason is that it is here assumed that transmission of the association_grant is only possible once per superframe, in the BCH time-slot.)

3.5.3 Flow management

In [WIN2D6138] a flow is defined as follows: “*A flow is a packet stream from one source to one or several destinations, classified by QoS requirements, source and destination(s).*” Moreover, in order to be able to distinguish different flows and hence support QoS requirements, a mechanism to uniquely identify flows must be used. Unfortunately flows cannot be distinguished with the information available in the data link layer not to mention in the physical layer. Information from higher layers is needed, in order to be able to decide when a new flow or synonymously connection shall be established and released respectively. One possibility to identify different flows uniquely is the quadruple of source IP address, destination IP address, source port number and destination port number. This approach would make it necessary to have a kind of convergence layer on top of the WINNER system, which is able to read the TCP/IP- and UDP/IP-headers. Furthermore the WINNER system has to provide a cross-layer interface for QoS aware requests by e.g. the application on top of the TCP/UDP/IP protocols.

Even if it is decided how to distinguish the different flows, it is still a challenge to handle, i.e. establish and release the flows, especially in the WINNER case supporting multiple hops and in addition multiple modes.

[1] The assumed super-frame structure of WINNER II is in its final form in [WIN2D61314] modified so that the RACH channel, used for initial access, is placed within the beginning of the main part of the super-frame, rather than in the preamble, as was assumed in WINNER I and in the test scenario of [WIN2D6137]. This results in only minor differences with respect to the timing of the association signalling.

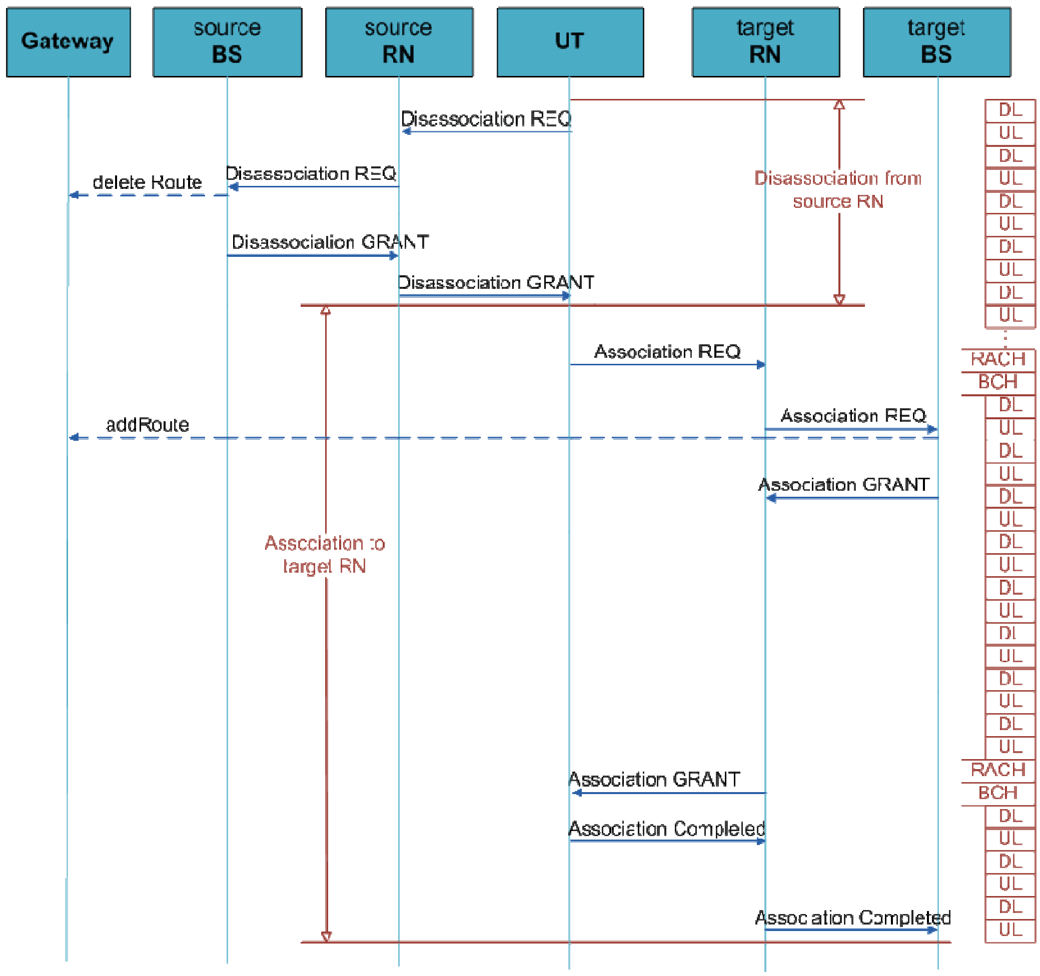

Figure 3-10: Association signalling during inter-cell handover.

In the investigations below, it is assumed that there is only one active flow between a UT and a BS, also in the case of being connected via a RN. The End-to-End ARQ mechanism in the RLC of the BS and UT respectively handles its instances based on this flow. Since there is only one flow between a UT and a BS, this flow is directly established during the association procedure. In case of a handover the end-to-end ARQ mechanism distinguishes between an *intra-cell* and an *inter-cell* handover.

- In case of an inter-cell handover, all packets in the ARQ buffers belonging to the current flow are deleted. A possible ARQ mechanism in the higher layers, e.g. in TCP would be in charge of re-requesting them. A more sophisticated handover procedure could send these packets to the new BS via the backbone.
- In case of an intra-REC handover, i.e. inter-mode with the same RAP or between a RN and its serving BS and vice versa, the packets in the ARQ buffer are preserved, since the flow does not change in this case.

3.5.4 Mode detection, selection and switching

Availability of a mode means that both the UT and the RAP support this mode so that they can communicate with each other via this mode. To know whether one of its supported modes is also available at the RAP, the UT listens to the BCHs. Different RAPs transmit their BCH on different OFDMA sub-carriers, so that UTs can receive them simultaneously. The BCH is mode dependent. The RAP sends broadcast messages via the BCH at the beginning of each super frame. The UT listens and evaluates each received BCH. Thus, for each mode the UT can have a set of received BCHs from different RAPs. The criteria used for the BCH evaluation is the SINR. The UT stores every received BCH with the SINR and the RAP ID and periodically, here every 0.01s, determines the best RAP. There are two thresholds for the mode detection, one for the detection (here: 0dB) and one for the disassociation (here: -1dB) (see Figure 3-11). The hysteresis avoids so called “ping-pong handovers”.

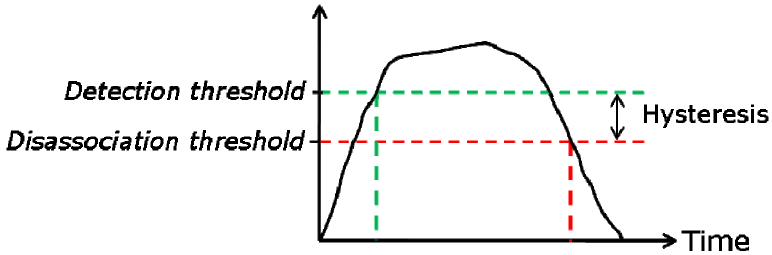

Figure 3-11: Mode detection and disassociation thresholds.

As a consequence of the mode detection information about the detected mode is stored and deleted respectively and if necessary a mode selection and switching is done.

Due to the fact that TDD is to be used in Microcellular and Indoor test scenarios and FDD in the Base Coverage Urban test scenarios, the mode selection strategy is as depicted in Figure 3-12. TDD is chosen if available, otherwise FDD is used. As a result of the mode selection the mode switching can be triggered by either the detection of a new mode, i.e. with the above assumptions inter-mode handover from FDD to TDD, or by the loss of coverage of the active mode, i.e. with the above assumptions inter-mode handover from TDD to FDD.

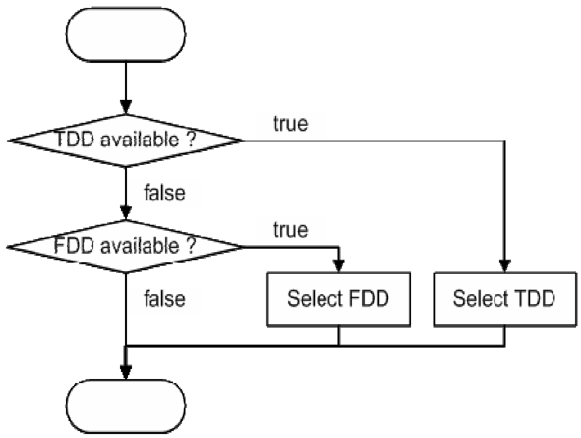

Figure 3-12: Mode selection strategy.

3.6 Interference mitigation

Resource management and inter-cell resource partitioning can be either static, where the resource allocation across neighbouring cells remains fixed over time, or dynamic in order to adapt to variations in traffic load or the user distribution. In the former case, inter-cell resource partitioning is achieved with fixed frequency reuse patterns, where typically the frequency reuse increases with the distance from the BS. As a dynamic approach interference management based on the busy tone concept is presented, where the time-scale for inter-cell resource assignment is in the order of one frame.

While for wide area a grid of beam (GoB) was shown to be very effective in mitigating inter-cell interference [WIN2D473], for Metropolitan area a multi-user MIMO precoding scheme, that relies on high median SNR and instantaneous CSI at the transmitter, is instead the choice for spatial processing, as described in Section 3.2 and [WIN2D341]. Hence, inter-cell interference avoidance and resource partitioning are effective means to ensure sufficiently high SINRs required for multi-stream spatial processing.

The street canyons of the Manhattan grid deployment generate only a small number of dominant interferers. Consequently, spatial receiver processing and in particular interference rejection combining (IRC) as described in [WIN2D341], provides larger gains in MA compared to WA. This enables the UT to cancel out much of the interference through IRC spatial processing, which should particularly support cell-edge users, and users with low SINR. Due to the same reasons inter-cell interference cancellation (IIC) which is investigated for WA in [WIN2D471], also benefits from the Manhattan grid deployment. As most of the interference originates from only 1 or 2 sources, IIC will exhibit more significant gains in MA. Also for the uplink, IRC can provide significant performance enhancements due to its ability to combat inter-cell interference, see section 4.2.2 for results on that.

3.6.1 Resource Partitioning

Static resource partitioning is achieved through Soft Frequency Reuse (SFR) or Fractional Frequency Re-use (FFR). In the case of SFR power masks in the frequency domain are assigned to each radio access point (RAP). Thus, SFR enables frequency reuse one and at the same time each RAP has high power resources with reduced interference available to schedule UT in the border area with other RAPs. FFR typically involves a sub-band simultaneously used by all cells, while the allocation of the remaining sub-bands is coordinated among the neighbouring cells in order to create sub-bands with a lower inter-cell interference. In [WIN2D472] static resource partitioning with an inner ring with frequency re-use of 1, and an outer ring with frequency reuse of 3 was studied for the wide area deployment scenario. The corresponding reuse 3 pattern for Metropolitan area is illustrated in Figure 3-13. With this reuse pattern LoS interference from adjacent BS is completely avoided. Hence, the resource partitioning schemes devised for wide area can be applied to metropolitan area as well.

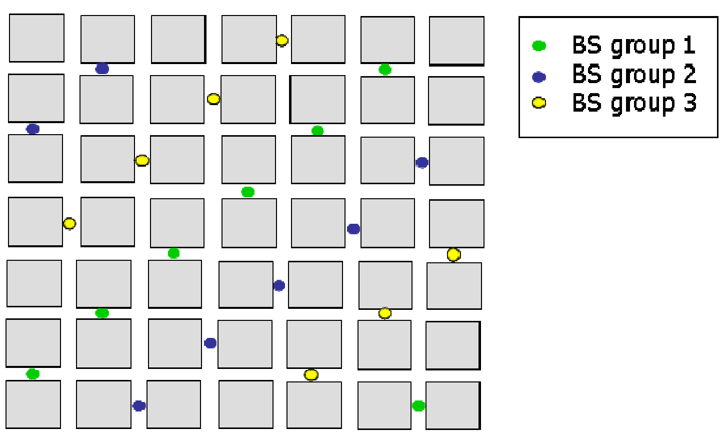

Figure 3-13: Static Resource Partitioning for the Manhattan Grid deployment scenario.

Resource partitioning is a central element of the RRM framework for relay enhanced cells (REC) described in Section 3.4.1. In the reference relay deployment, RNs are added to the BS deployment, depicted in Figure 3-13 resulting in a higher density of RAPs. Thus, the received interference originates from more than 1-2 sources and resource partitioning is an effective way to coordinate the interference. Further, the simulation results in Section 4.4.1 illustrate, that SFR can even increase the average throughput in a REC by utilising SFR and a strong BS-RN link. The BS can schedule transmissions to RNs on chunks with low power and transmissions to UTs on high power chunks, which increases the overall throughput.

3.7 Spectrum technologies

This section presents the spectrum functionalities developed within WINNER project. First the considered spectrum scenarios are discussed, followed by an introduction of the WINNER spectrum management functions.

3.7.1 WINNER spectrum scenarios

The World Radiocommunication Conference, WRC-07 is expected to identify bands for IMT-Advanced. At the present moment the candidate bands identified in ITU-R WP 8F are: 410-430 MHz, 450-470 MHz, 470-806/862 MHz, 2300 - 2400 MHz, 2700 - 2900 MHz, 3400 - 4200 MHz 4400 - 4990 MHz. The ITU-R studies show that a considerable amount of spectrum is needed to provide the total capacity required in the future and to meet the high data rate requirements imposed on the systems [ITU-R M.1645], [ITU-R M.2078]. For these reasons, the bands of main interest for WINNER are bands that can provide large enough portions of spectrum to have several 100 MHz channels next to each other. Therefore, the frequency bands between 3-5 GHz have been determined as first choice candidates, more precisely 3.4-4.2 GHz. Presently satellite systems are deployed in these candidate bands as well, and therefore sharing with these systems will be required. In the following sections spectrum scenarios are detailed for the different WINNER deployment scenarios, based on the assumption that a band dedicated to WINNER is needed for guaranteed service (for example initial access and certain control signaling) and that shared extension bands can be used to achieve the high performance objectives.

For the metropolitan area scenario the most important requirement with respect to spectrum issues, is ubiquitous coverage. A “safe mode” operation in MA is possible due to the availability of dedicated NB or WB spectrum. This specific spectrum band may be dedicated either to WINNER or to operators depending on the regulatory policy. These bands may be located either within the candidate band or in the lower carrier frequency, e.g. the current mobile cellular band. The “enhanced mode” is feasible by sharing the spectrum with for example the Fixed Satellite Services (FSS), a major potential primary system for WINNER. A solution where the “safe” and “enhanced” mode would be operating in similar spectrum region hence avoiding a fragmentation of the spectrum is preferred due to technical and cost reasons. Within the exclusion zones required to protect the FSS, the WINNER system can not operate in the same channel and may need to share the spectrum with another ITU primary service different than the FSS e.g. DVB-T, Fixed Services (i.e. microwave links).

Physical propagation properties intrinsic to Metropolitan Area environment may render the deployment easier in shared spectrum than for Wide Area scenarios. This is due to the natural urban shield which exists and facilitates the small exclusion zone when the spectrum is to be shared with FSS. As the MA scenario is primarily operated in TDD mode, the coexistence of FDD and TDD system is also to be considered for that scenario since overlapping between WA and MA deployment is inevitable. In the case of TDD mode, the RANs are synchronized. Sharing and co-existence mechanisms between RANs on the shared spectrum (with FSS) are necessary. The MA scenario will probably be a hybrid combination between a centralised and a distributed spectrum control.

In general the WA scenario is very similar to the MA scenario. FDD mode, without time synchronization between RANs is mainly considered, for the WA deployment. FSU between RANs on FDD mode is an open issue. FSU between different duplex modes (TDD/FDD) is also foreseen between spatially overlapping cell layers and/or between neighbouring cells of the WA and MA deployments. It is likely that such WA scenario implies centralised spectrum control. The possible sharing scenario is illustrated in Figure 3-14.

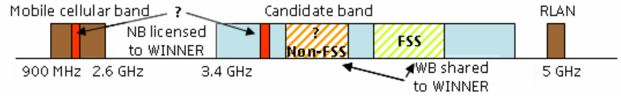

Figure 3-14: Example of a scenario for WA and MA deployment. In WA, the main operation is to be done for NB, but opportunities in using WB spectrum exist. For MA deployment, main emphasis is the usage of the WB spectrum opportunities given in the FS/FSS band (Figure not to scale).

Due to the nature of the local area deployment, two spectrum scenarios examples can be considered. Similarly to the WA and MA, the FSS band may be used. Due to the fact that LA is mainly for indoor use with short range applications, the FSS spectrum is a very attractive candidate. A “safe mode” operation is still required for the LA deployment. In addition to the candidate band, the RLAN band in the 5 GHz region may be used by WINNER to provide “enhanced-mode” as a complement or alternative to FSS shared band. This is illustrated in Figure 3-15.

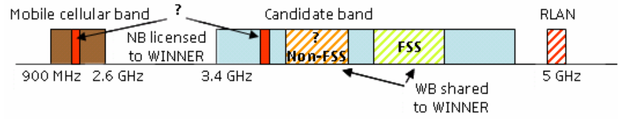

Figure 3-15: Example of a scenario for LA deployment WB spectrum is available in the candidate band and limited extra band can be used in the RLAN band in the 5 GHz region (Figure not to scale).

3.7.2 WINNER Spectrum Resource Management Functions

3.7.2.1 Spectrum functions in a nutshell

A conceptual overview of the spectrum control functions is presented in Figure 3-16. The figure illustrates the main interactions between the spectrum control functions and related RRM functions in WINNER. The most salient spectrum control functions are summarised in Table 3-2 [HOOLI2005]. Here it is assumed that only one GW is assigned to a certain location area.

Spectrum Sharing	**Flexible Spectrum Use**
Spectrum sharing functions	Spectrum assignment functions
This group includes: • Vertical Sharing 1 (VS1) • Vertical Sharing 2 (VS2) • Horizontal Sharing with Coordination • Horizontal Sharing without coordination	This group includes: • Long Term Assignment (LT) • Short Term Assignment (ST)

Table 3-2 Spectrum functionality classification

Under the Spectrum Sharing umbrella, four different schemes have been investigated. They are based on the access rights of each system to the shared spectrum. If one system has a priority access to the spectrum over the other, then vertical sharing schemes are applied. In such a case, if the WINNER system is the primary system then this results in Vertical Sharing 1 scheme (VS1). If the WINNER system is a secondary system and has higher priority access rights compared to any other secondary systems, then Vertical Sharing 2 scheme (VS2) is defined. If both systems, i.e. WINNER and other, have same access rights to the spectrum then this results in horizontal sharing schemes. The horizontal sharing situation maps into two different sharing schemes. The first horizontal scheme assumes that the systems contending for spectrum can coordinate with each other to enable efficient spectrum allocation. This is called Horizontal Sharing with Coordination (HwC). The second scheme is considered when both systems do not coordinate with each other in the framework of spectrum sharing functionalities. This scheme is called Horizontal Sharing without Coordination (HwoC). The coordinated horizontal sharing introduces QoS agreement to the users compared to the uncoordinated horizontal sharing case.

Once the spectrum is made available to the WINNER system, its allocation within the WINNER RANs is investigated in the spectrum assignment scheme. WINNER considers a Long Term (LT) and Short Term (ST) spectrum assignment strategy to take advantage of the changing nature of the spectrum availability and the traffic demand in different parts of a multi-operator environment. The LT scheme assigns the spectrum at a higher level of geographical granularity between multiple RANs. During the LT assignment functional procedure the spectrum is negotiated over a longer time scale, i.e., in the order of tens of minutes, over the WINNER deployment of operation. The ST assignment acquires the fine tuning of the spectrum assignment at the cell level. This is performed at shorter time scales than in LT assignment, i.e., the ST assignment negotiation of spectrum is performed over time periods as frames of 100 ms in duration.
Due to the large difference between the WA, MA and LA deployment, the functional grouping of Figure 3-16 does not indicate any preferred mapping of functions to the logical entities in WINNER RAN. Functions belonging to the same group may be located to different logical nodes.

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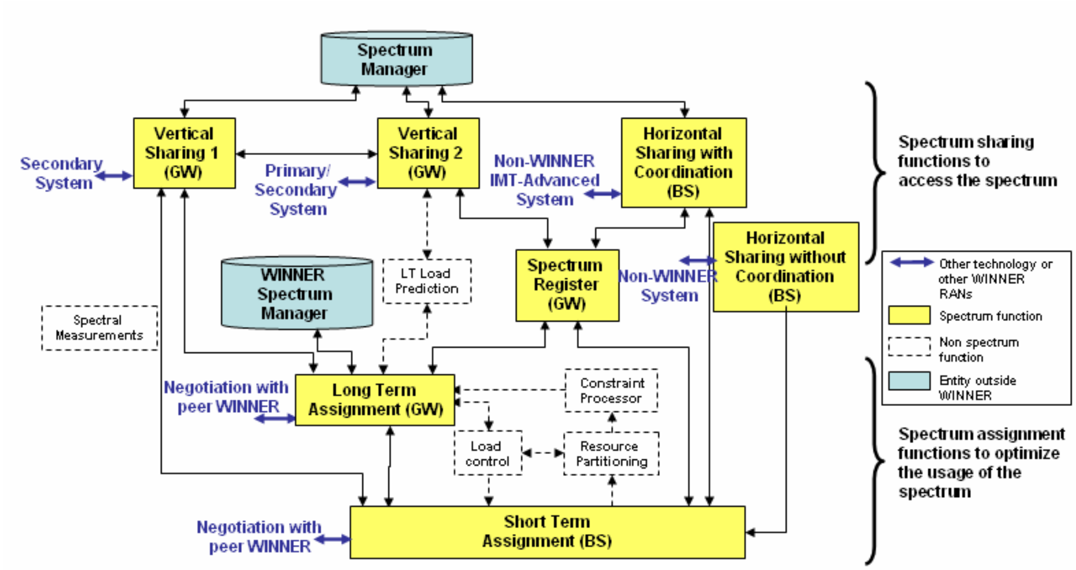

Figure 3-16: Illustration of the interactivity of the spectrum sharing and spectrum assignment function in the WINNER concept.

In general, spectrum sharing functions consist of concurrently triggered procedures. A normal spectrum control procedure (e.g. actualization of a given resource set, measurement collection, etc.) is the result of several individual action calls. Thus, in practice there is not a clear boundary among the spectrum control functions, and it is essential to consider the definition in details.

3.7.2.2 Sharing and Co-existence Functions

Vertical Sharing 1: WINNER is the primary system

This function is considered when WINNER is the primary system. WINNER may assist a secondary system by sharing its primary spectrum resources. This is feasible by signalling its unused spectrum resources via its broadcast channel (BCH), by means of a universal or customised broadcast radio beacon.

Depending on the expected incentives for the WINNER RAN, unused spectrum could be actively created. The responsibility for creating unused-spectrum belongs to the overall resource optimization which involves the LT and ST Assignment functions. Since the spectrum resources leased to the secondary systems are operator-wise, each operator can use part of its prioritised or its assigned common pool resources.

Vertical Sharing 2: WINNER is the secondary system

When the WINNER RAN is the secondary system, it has to control its emissions from both the BS and all the user terminals (UT) in order to avoid interfering with the primary system. More generally, the secondary system may adopt a dynamic, opportunistic use of the unused part of the spectrum. For that purpose, considerable knowledge about the deployed primary system may be required.

Besides the information acceded through the Spectrum Manager, spectrum related measurements done at physical layer (BSs and UTs) might be compiled. These measurements are facilitated when the primary system emits a standard beacon periodically. The compiled information, i.e. measurements, site information, location, protection requirements of the primary system downloaded from databases, etc is transformed into a set of transmission constraints defining and characterizing the shared spectrum, e.g. exclusion zones in the context of sharing with FSS.

In non-loaded conditions, and depending on incentives for the WINNER RAN, the WINNER system may lease its identified unused spectrum to other secondary systems since WINNER may have better capabilities in accessing the spectrum compared to other secondary or sub-secondary system. In this case of spectrum “re-sharing”, the regulatory perspective might require extra mechanisms.

Horizontal sharing with coordination

The involved systems (i.e. WINNER and non-WINNER RATs) have equal access rights to the spectrum, and coordinate their spectrum access based on a set of predefined rules (spectrum sharing rules) that all the involved systems are submitted to. Each system adapts its transmission to mitigate interference to others by applying constraints issued from common policies shared by all the candidate systems or determined on the basis of the previous coordination phase. Location services and measurements of other systems radio activity might be useful for a better coverage estimation of the other system resulting in a better coordination in terms of actual mutual interference. These measurements are facilitated by using special purpose mutual beacon signals; therefore access to the BCH at MAC layer is expected for this function.

Similarly to VS2 function, the obtained shared spectrum indicators are conveyed to LT Assignment function via the Spectrum Register. In the case that the Spectrum Register entity is rather centralized and slow, for the more dynamic opportunistic LA approach, direct communication from the Horizontal Sharing function to the ST function might be implemented.

Horizontal sharing without coordination

The HwoC scheme would consider e.g. the RLAN license exempt band around 5GHz. It is known that the current unlicensed exempt bands are limited from interference protection point of view. They are also likely to be congested with regard to the number of services allocated to them. Therefore, there is a need for the spectrum sharing functions to bring discovery mechanisms in order to reach for an opportunistic use of the spectrum. Nevertheless, efficient detection of white spaces, i.e., unused spectrum, is not easy task due to problems of the discovery of hidden nodes or energy-based detection mechanisms. Since QoS cannot be guaranteed for any system, it is important to understand whether WINNER can accept such QoS in LA only.

3.7.2.3 Spectrum Assignment

Long Term Assignment

The LT Assignment coordinates partly the usage of the spectrum between WINNER RANs. This function coordinates and negotiates the spectrum assignments between multiple WINNER RANs for large geographical areas with spatial granularity of cluster of cells. LT assignment entity is located at the GW. The spectrum assignments are updated periodically and at a slow rate, that is, in time frame of several tens of minutes. It can be used also to provide dynamic spectrum assignments between WINNER RANs. This entity is also responsible for the coordination between the WINNER TDD and FDD modes. Inter-RAN coordination is achieved through the direct negotiations between peer LT assignment functions in different WINNER RANs.

The LT Assignment could be extended to support the coordination of (static) spectrum assignments over the country borders. This requires signalling between the WINNER Spectrum Managers in the neighbouring countries, providing sufficient information to establish signalling between the related LT Assignments over the IP network, and over the country border. However, another natural option is that the over-the-border coordination is included fully to WINNER Spectrum Managers.

Short Term Assignment

This function controls the short-term and local, i.e. cell-specific, variations of the large-scale spectrum assignments. Hence, it enables faster adaptation to the local traffic load variations and geographically more accurate spectrum assignments than the LT Assignment. The assignments are performed in the time scale of several MAC super-frames, i.e. 100ms to several minutes. Due to the above cell wise functionalities the location of the ST assignment is at the BS.

The ST Assignment requests spectrum resources from other WINNER RANs after being triggered by the LT Assignment or by preventive load control. The fundamental reason for developing ST assignment is that in the case of two RANs providing the exact same services, traditional handover between RANs to support the load condition could be envisaged, but operators may be reluctant for such a handover of users , i.e., the operators would prefer to keep the UTs connected to their own RAN. Further in the case that increasing the spectrum of one RAN would result in enhancing the service capabilities, e.g. in terms of capacity provided to the UTs, spectrum assignment becomes a necessity for creating new services with better user QoS capabilities.

4. Performance assessment results of WINNER system in Metropolitan Area deployments

4.1 Overview

This section presents performance assessment results of WINNER system design solutions targeted for metropolitan area deployments of WINNER system. The related design solutions were presented in section 3. Following results are covered in this section

- Section 4.2: spatio-temporal processing
  - system level performance assessment of multiantenna schemes for metropolitan area deployments.
- Section 4.3: network synchronization
  - Simulations on the network synchronization delay with the proposed, self-organizing synchronization method
- Section 4.4: relaying
  - Performance comparison of preferred relay deployment and BS only deployment in metropolitan areas
  - Performance assessment of MIMO cooperative relaying and multi-user scheduling for REC with coordination
  - Cost analysis for relay deployments in a metropolitan area scenario
- Section 4.5: performance of various scheduling strategies.
  - Performance assessment of a selection of schedulers for adaptive OFDMA
- Section 4.6: multi-mode handover
  - Performance assessment of inter-mode, inter-REC or intra-REC handover
- Section 4.7: semi-static resource allocation
  - Assessment of MAC overhead reduction when Frame Descriptor Tables are used.
- Section 4.8: spectrum management.
  - Performance assessment of short term spectrum assignment in metropolitan area deployment and spectrum scenario

Most of the results are compliant with the common performance assessment assumptions for metropolitan area deployments of WINNER system, presented in [WIN2D6137], and summarized in section 2.2. Some of the results are obtained by using simplified performance assessment assumptions, in order e.g. to reduce the algorithm modelling complexity in the system simulator implementations.

4.2 Spatio-temporal processing

In this section, system level simulation results illustrating the performance of the proposed metropolitan area reference design spatio-temporal processing solutions are provided. The simulations follow to a large extent the deployment, system, and simulation assumptions for the microcellular scenario given in [WIN2D6137] and summarised in Section 2.2. However, the focus of the investigations has been on spatio-temporal processing techniques, hence some assumptions may differ. In case major deviations are made, they are clearly stated in the text.

4.2.1 Downlink

4.2.1.1 SMMSE multi-user MIMO precoding

In this section we present system level simulation results of SMMSE multi-user MIMO precoding in the microcellular scenario. It should be noted that the study originally was carried out to assess the impact on velocity on multi-user MIMO techniques, hence a number of simplified assumptions compared to the ones in [WIN2D6137] have been adopted, and the results cannot directly be compared to others and should rather be seen as illustrations of the achievable performance.

The number of users is variable and depends on the total number of antennas that can be estimated at the base station and the number of antennas at the user terminals. Assuming that each user terminal is equipped with two antennas and that 9 antennas can be estimated per contention band (3 antennas per chunk × 3 chunks in UL slot = 9 antennas, assumed channel being constant over one frame DL+UL), the number of users is four per competition band. Users are scheduled using Round Robin. Coding and modulation schemes are chosen based on the SINR prediction per chunk. Data block length is chosen such that a coded block can fit in one chunk. Data is encoded using a punctured convolutional code with rate 1/3. The number of the antennas at the base station is eight, and the maximum number of spatial layers is four. It should also be noted that in this study omni-directional antennas are used, hence only one cell per site is assumed.

The results are presented in Figure 4-1 and Figure 4-2 below, showing complementary CDFs of cell and user throughput, respectively. It can be seen that the median cell throughput is around 490 Mbps for 3 km/h, compared to 260 Mbps for SISO. The median user throughput is around 24 Mbps, compared to about 9 Mbps for SISO. For user terminal speed of 50 km/h the median cell throughput is 265 Mbps and the median user throughput is around 10 Mbps, i.e. similar to SISO.

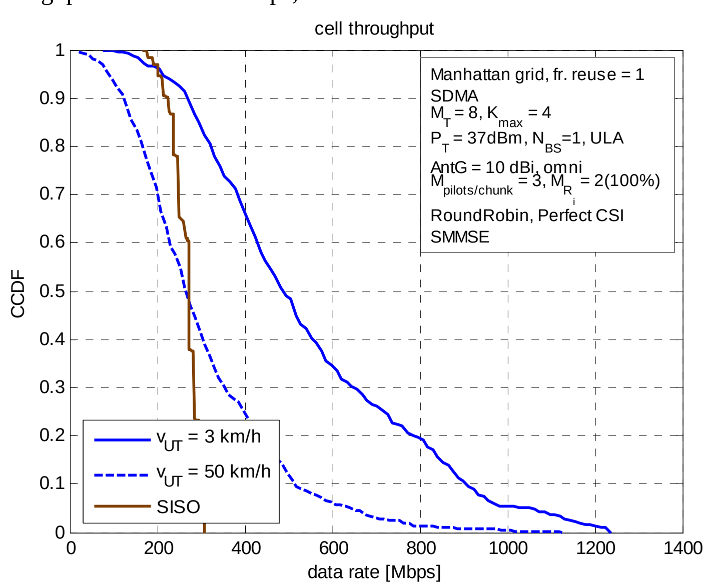

Figure 4-1: Complementary CDF of cell throughput.

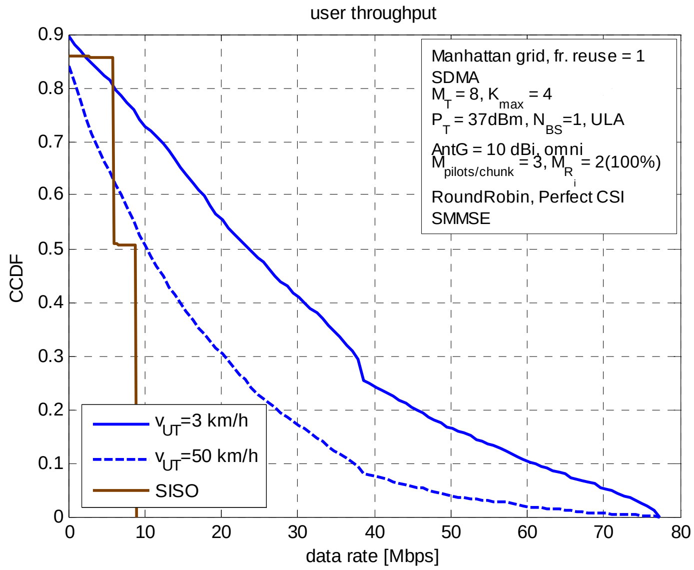

Figure 4-2: Complementary CDF of user throughput.

Thus, it can be concluded that SMMSE multi-user MIMO precoding performs well for low user velocities (3 km/h), providing 80 % higher cell throughput than a SISO system and 160 % higher user throughput. This is due to the TDD transmission and low speed that facilitates the availability of very accurate CSI at the base station. It should also be mentioned that the simplified assumptions with respect to modulation and coding most probably underestimates the SMMSE gains at low velocities. However, at higher user mobility, e.g. 50 km/h, the performance of SMMSE multi-user MIMO precoding degrades and is similar to that of a SISO system.

The requirements in [WIN2D6114] state a downlink spectral efficiency of 3 bps/Hz/cell for metropolitan area. In this study, the median cell spectral efficiency of SMMSE multi-user MIMO precoding at user speed of 3 km/h is 4.9 bps/Hz/cell. However, due to the somewhat deviating assumptions this figure should more be seen as indicative rather than absolute. In any case, the figure will be larger in case two sectors (cells) per site [WIN2D6137] are used, since it can be expected that the extra antenna gain of directional antennas will be of benefit for the multi-user MIMO precoding scheme. Also the use of a channel aware scheduler is expected to improve performance.

4.2.1.2 Adaptive Linear Dispersion Codes

Adaptive linear dispersion codes (LDC) are investigated in downlink in metropolitan area through system level simulations of class III. The LDCs here cover a 2x2 system with Alamouti space-time block coding (STBC) for single stream transmission and V-BLAST for dual stream transmission. The adaptation for LDCs is based both on the eigenvalues of the MIMO channel and on the received SINR, as described in Section 3.2.1.1. Basically the capacity is calculated from these two factors for selecting transmission rank. The adaptation period is one frame and the LDC is selected for the full user bandwidth, i.e. non-frequency-adaptive transmission is assumed. We assume that perfect channel and SINR information are known at the transmitter due to channel reciprocity. SISO and SIMO MRC are also simulated for comparison. The deployment scenario and system parameters are the ones specified for the microcellular scenario, i.e. Manhattan grid deployment, in [WIN2D6137], but only outdoor users are considered. Some simulation parameters are given in Table 4-1.

Channel model	B1 [WIN2D111]
User velocity	50 km/h
Modulation and coding	BPSK LDPC coding 1/2, 2/3; QPSK LDPC coding 1/2, 2/3, 3/4; 16QAM LDPC coding 1/2, 2/3, 3/4; 64QAM LDPC coding 2/3, ¾

Retransmission	HARQ with chase combining
Scheduling	Proportional fair, ideal link adaptation
Traffic model	Full buffer
LDC adaptation granularity	One frame
Receiver	MMSE or MRC
Channel estimation	Ideal
CSI and SINR at Tx	Perfectly known
Adaptive in frequency	No

Table 4-1 Simulation assumptions for adaptive LDC in downlink

Figure 4-3 and Figure 4-4 show simulation results for average cell spectral efficiency and 5-percentile user throughput, respectively. Here the number of users per cell is fixed and equals to 5. The overhead considered only includes common pilot and two symbols per chunk per antenna are assumed for it. Single stream transmission and receive diversity with MRC can provide 34 % gain over SISO case. The user throughput gain from MRC is also quite large. Adaptive LDC provides 42 % cell gain over 1x2 MRC thanks to possible dual stream transmission. However, regarding the 5-percentile user throughput, only a small gain is obtained through adaptive LDCs.

The conclusion from the study is similar to what was shown already in [WIN2D341]; the Manhattan grid deployment results in a high median SINR in the downlink due to the line-of-sight channels arising in the narrow street canyons. Therefore, for adaptive LDCs it has been seen that the number of users benefiting from dual stream transmission is increased, which results in large cell throughput improvement, although only a small gain from dual stream transmission is obtained for cell edge users. The cell spectral efficiency of the 2x2 LDC scheme investigated is about 1.8 bps/Hz/cell. This is below the WINNER system requirement of 3 bps/Hz/cell, but an extension to a 4x2 scheme would potentially meet the requirement. Also to increase the number of receive antennas to four would be beneficial, as illustrated by the 2x4 and 4x4 configurations investigated for the metropolitan area in [WIN2D341], which however makes the UT more complex.

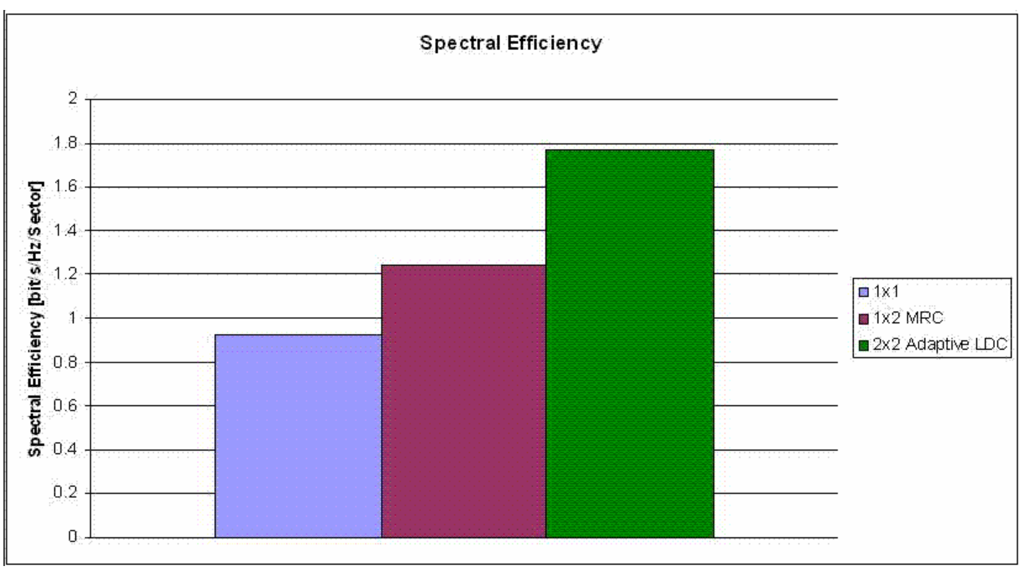

Figure 4-3: Spectral efficiency per cell in metropolitan area downlink in case of 5 users per cell.

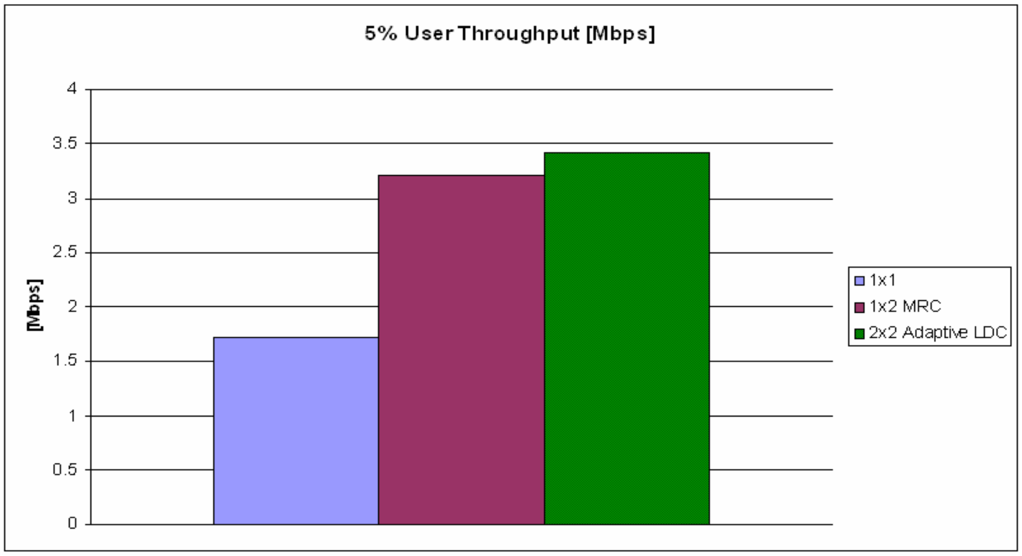

Figure 4-4: 5-percentile user throughput in metropolitan area downlink in case of 5 users per cell.

4.2.2 Uplink

4.2.2.1 Alamouti space-time block coding and receive diversity combining

System level simulations are performed in uplink using a class III system level simulator. The basic scenario simulated is Manhattan grid deployment according to [WIN2D6137], but only outdoor users are considered. The most important simulation assumptions are summarised in Table 4-2. Alamouti space-time block coding (STBC) is the baseline scheme in uplink and its possible gain over single transmit antenna and with different receiver combining methods at the base station are investigated. The spatial scheme and antenna configurations investigated include:

- SISO: 1 Tx and 1 Rx
- SIMO
    - 1 Tx and 2 Rx MRC
    - 1 Tx and 2 Rx IRC
    - 1 Tx and 4 Rx MRC
    - 1 Tx and 4 Rx IRC
- MIMO
    - 2 Tx Alamouti and 2 Rx MRC
    - 2 Tx Alamouti and 2 Rx IRC

Channel model	B1 [WIN2D111]
User velocity	50 km/h
Modulation and coding	BPSK LDPC coding 1/2, 2/3; QPSK LDPC coding 1/2, 2/3, 3/4; 16QAM LDPC coding 1/2, 2/3, 3/4; 64QAM LDPC coding 2/3, ¾
Retransmission	HARQ with chase combining
Scheduling	Proportional fair, ideal link adaptation
Traffic model	Full buffer
Channel estimation	Ideal

Table 4-2 Simulation assumptions for Alamouti STBC and receive combining in uplink

Figure 4-5 and Figure 4-6 show simulation results for average sector (cell) throughput and 5-percentile user throughput, respectively. The overhead considered only includes common pilots, for these two symbols per chunk per antenna are assumed. SIMO with two antenna receive diversity and MRC can provide 46 % gain over SISO case and IRC still can provide around 18 % additional gain due to possibly considerable interference level in uplink. With four receive antennas, the gain of MRC over SISO is up to 80 %, and IRC provides 21 % gain over MRC. The user throughput gains for MRC and IRC are also quite significant. Alamouti coding only provides 7 % and 5 % sector throughput gain over 1 Tx with 2 Rx MRC and IRC, respectively, whereas for the 5-percentile user throughput, almost no gain is obtained by Alamouti coding. It should however be noted that these results are obtained with a user mobility of 50 km/h, with a lower mobility the gains of Alamouti coding is expected to be somewhat more pronounced. A condensed summary of the values of spectral efficiency per cell and 5-percentile user throughput can be found in Table 4-3

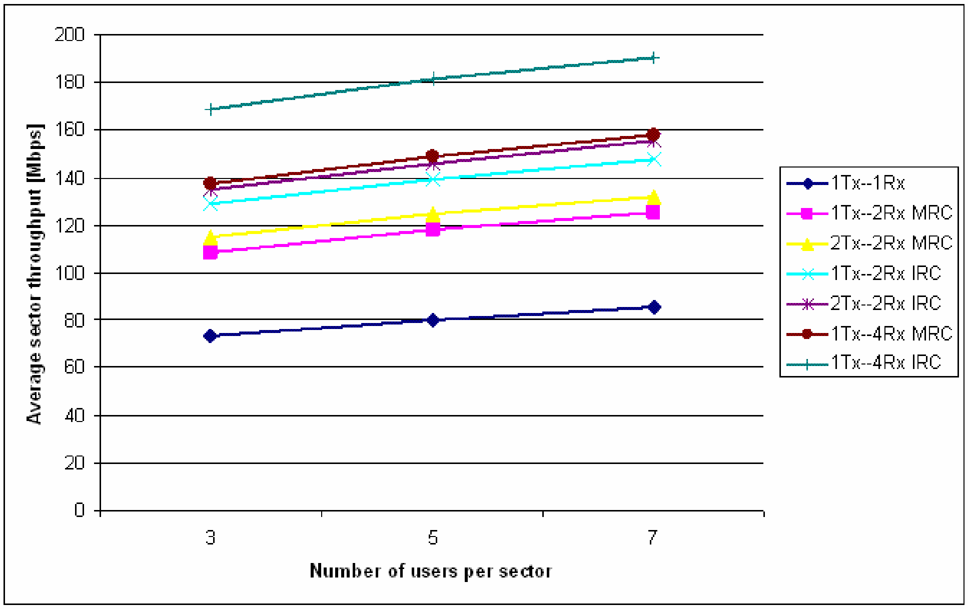

Figure 4-5: Sector throughput for uplink in metropolitan area.

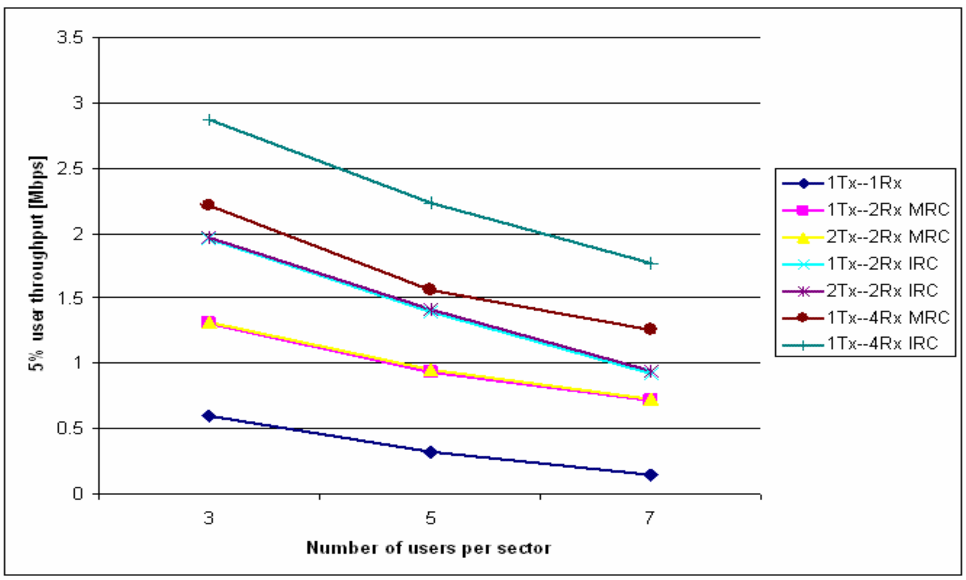

Figure 4-6: 5-percentile user throughput for uplink in metropolitan area.

Case	Spectral efficiency (bps/Hz/cell)	5-percentile user throughput (Mbps)
1Tx 1Rx	0.80	0.33
1Tx 2Rx MRC	1.18	0.93
1Tx 2Rx IRC	1.39	1.39
2Tx 2Rx MRC	1.25	0.96
2Tx 2Rx IRC	1.46	1.41
1Tx 4Rx MRC	1.49	1.56
1Tx 4Rx IRC	1.81	2.23

Table 4-3 Spectral efficiency and cell edge user throughput in metropolitan area uplink with 5 users per cell

The basic conclusion is that in uplink receive diversity at the base station with MRC bring much gains for both cell throughput and cell edge user throughput. Furthermore, IRC instead of MRC improves the performance even further, due to the possibility for strong uplink interference in the narrow street canyons. The transmit diversity gain of the Alamouti baseline scheme is basically invisible for cell edge users although it still bring small improvement for median and high SINR users. Hence, the value of Alamouti transmission can be questioned, especially when considering the cost of the extra radio transmitter chain it requires. The recommendation is thus, as already stated in Section 3.2.1.2, instead to utilise antenna hopping for low velocities and single antenna transmission at higher velocities at the UT, and four antenna receive diversity with IRC at the BS. From Table 4-3 above, we see that this yields a cell spectral efficiency of 1.8 bps/Hz/cell, which meets the requirement of 1.5 bps/Hz/cell stated in [WIN2D6114]. In addition, further improvements are expected if uplink SDMA as suggested in Section 3.2.1.2 is realised. Unfortunately no metropolitan area results are available of that, but wide area results show gains [WIN2D61312].

4.3 Network Synchronisation

In the metropolitan area scenario, base stations and user terminals are placed on a grid. In order to make sure that the network is connected, i.e. there is a path between any pair of nodes, only user terminals that are placed at intersections participate to the network synchronisation scheme and transmit the UL Sync word. These nodes are able to link at least two base stations which are not in line of sight. An example of the considered topology is shown in Figure 4-7 for a three-by-three (3x3) grid. Base stations, indicated as black dots, are placed according to the pattern given in Figure 2-2, and 45 user terminals, marked as red dots are placed randomly at intersections. Links are shown between connected BSs and UTs.

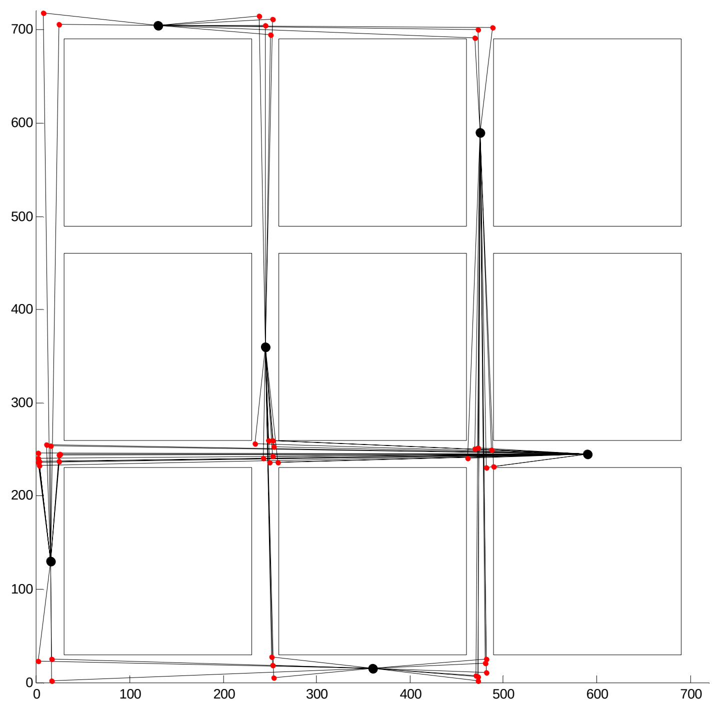

Figure 4-7: Considered Network Topology for a 3x3 blocks network and 45 UTs.

The following simulation results look at the time needed for the entire network to synchronise, i.e. all user terminals fire simultaneously before all base stations fire simultaneously, when nodes are placed on a grid of 3x3, 4x4 and 5x5 blocks. The time to synchrony T_{sync} is normalised to the duration a super-frame T_{SF}, and is evaluated for 5,000 sets of initial conditions, i.e. all participants initially commence with a uniformly distributed random clock value, as the coupling value at user terminals α_{UT} varies. Base stations parameters are set to: $\alpha_{\text{BS}} = 1.03$, $\beta_{\text{BS}} = 0.01$ for the coupling defined in Section 3.3.2.1, and $T_{\text{refr,DL}} = 40 \cdot T_{\text{s}}$ where T_{s} is the duration of an OFDM symbol. User terminal parameters are set to $\beta_{\text{UT}} = 0.01$ and $T_{\text{refr,UL}} = 30 \cdot T_{\text{s}}$. Figure 4-8 through Figure 4-11 show the cumulative distribution function of the normalised time to synchrony as the number of participating user terminal augments and for different values of the coupling parameter α_{UT}.

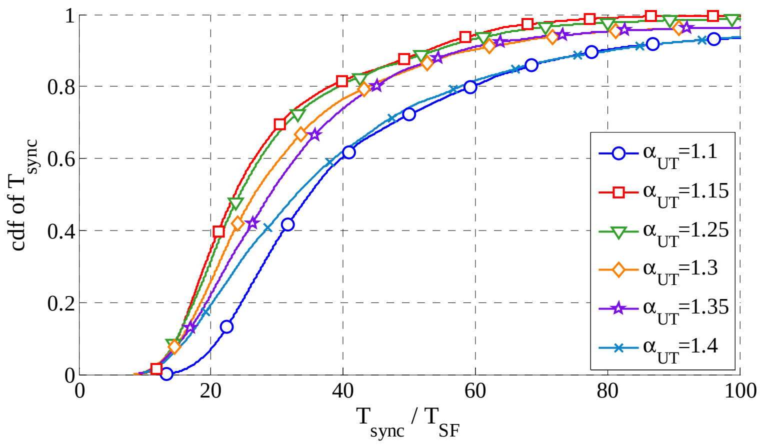

Figure 4-8: Metropolitan Area Results for a 3x3 grid and 60 UTs.

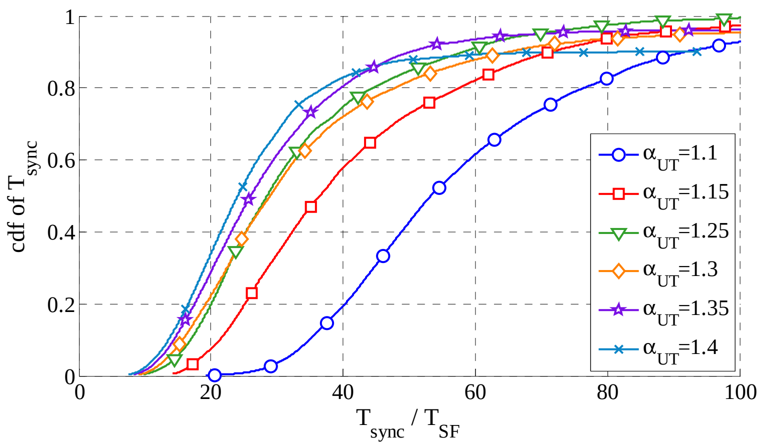

Figure 4-9: Metropolitan Area Results for a 4x4 grid and 60 UTs.

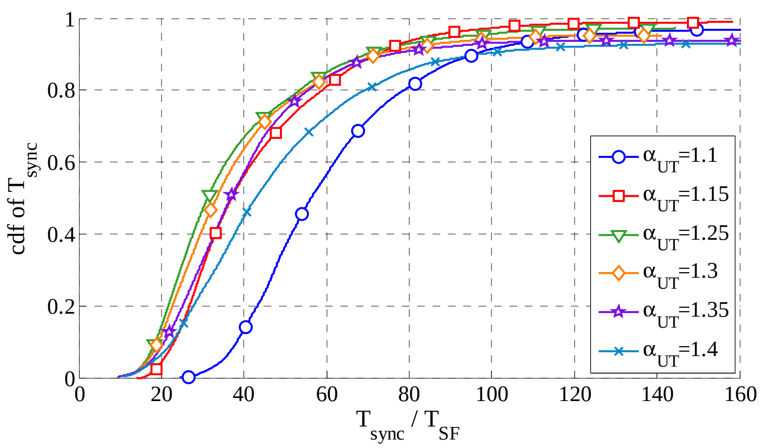

Figure 4-10: Metropolitan Area Results for a 4x4 grid and 80 UTs.

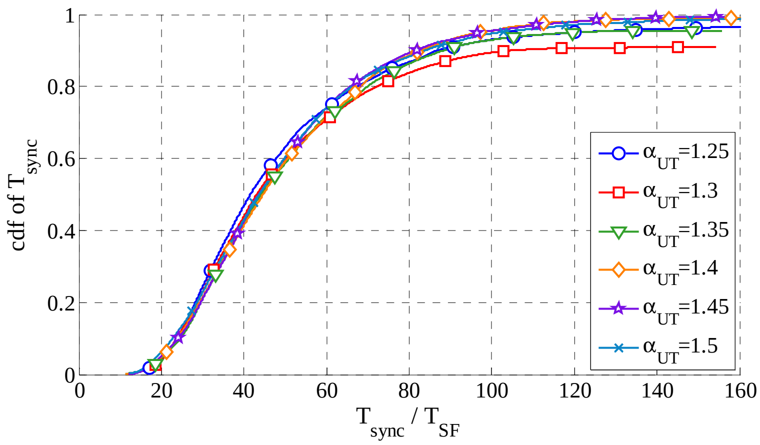

Figure 4-11: Metropolitan Area Results for a 5x5 grid and 80 UTs.

As the network size increases, the time to synchrony also rises. For a 3x3 grid, synchrony is reached within 50 periods in 90% of initial conditions, whereas it requires 80 periods for a 5x5 grid. In all cases, the time to synchrony can be considered to be relatively high, especially compared to the local area scenario, where synchrony is reached within 10 periods. Thus it is necessary to place reference nodes within the network, so that nodes can acquire a timing reference more quickly. Therefore it is possible to trade the number of reference nodes with a required time to synchrony.

4.4 Relaying

In this section we present numerical assessment results for the reference design solutions presented in section 3.4. Our results in section 4.4.1 indicate that interference coordination based on soft-frequency reuse together outperforms restrictive resource partitioning and reuse one in the frequency domain. The relay deployment achieves a 28% higher throughput than the BS only deployment. In section 4.4.2 we illustrate that MIMO cooperative relaying can potentially increase the throughput by up to 50% compared to single-path relaying. Further, in section 4.4.3 we present numerical assessment results that show the potential of the centralised multi-user scheduling scheme presented in section 3.4.3 to outperform distributed scheduling. Moreover, our cost studies in section 4.4.3 prove that relay deployments can be more cost efficient than BS only deployments for RN/BS cost ratios of one third to one fourth.

4.4.1 Comparison of preferred relay deployment with BS only deployment

As the results in [WIN2D352] have illustrated, the baseline relay deployment and static resource partitioning presented in [WIN2D6137] does not perform well. Therefore, we present preferred design and deployment options that improve the performance of the relay deployment illustrated in Figure 4-12 compared to the baseline design. The impact of the different design and deployment options on the average user throughput is presented in Table 4-5.

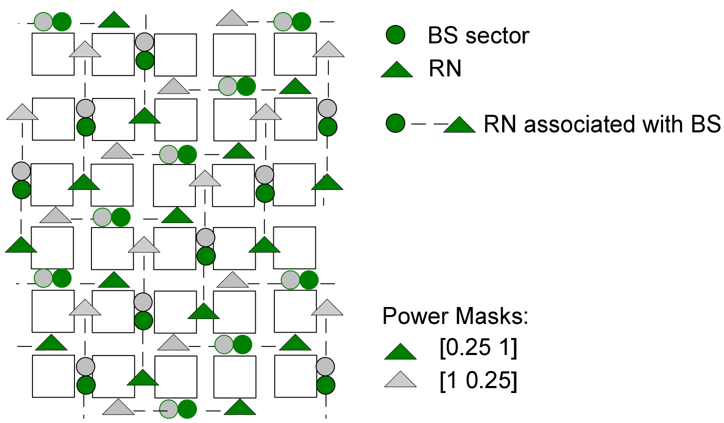

Figure 4-12: BS and RN deployment pattern with assigned power masks for soft frequency reuse (zoom).

In our simulations we use the B1 LOS path-loss and channel model for nodes in the same street and B1 NLOS for nodes in different streets [WIN2D111]. Further, we utilize a two stage scheduling approach similar to the approach described in [PPM+07]. A time domain scheduler guarantees fairness between the users. It selects the 6 users with the lowest average throughput in the last 200 ms. The frequency domain scheduler uses the proportional fair criteria or the phased scheduler in the soft frequency reuse case to improve the spectral efficiency. The user throughput statistics have been collected every 400 ms. The results are collected from 4 cells in the center, and 21 cells around the center cells are fully modelled including scheduling and user traffic. The rest of the 97 cells are modelled as interfering cells, i.e. the user traffic and the scheduling are not modelled. The user density is kept constant in all the simulations and the user terminals move only on streets and in areas served by the active cells. The active cells cover about 0.6 km^2 and the monitored cells about 0.12 km^2. Selected simulation parameters are presented in **Table 4-4**.

BS Tx power	30dBm	MCS set for user data	BPSK 1/2, QPSK 1/2, 16 QAM ½, 2/3, 3/4, 64 QAM ½, 2/3, 3/4
RN Tx power	30dBm	MCS set for control data	QPSK & BPSK 1/2 for BCH and RACH
BS antenna	directional with 70° beamwidth	ARQ	Yes (No HARQ)
BS antenna gain	14dBi	Time Domain Scheduling	Equal Throughput
BS No. sectors	2	Frequency Domain Scheduling	Proportional fair
RN antenna towards	directional 70°	Time Domain Scheduling	Round Robin/Equal

BS	beamwidth		Throughput
RN antenna towards UT	omni-directional	Initial RAP Selection	RAP with highest signal strength
RN antenna gain towards BS	14dBi	Cell reselection handover	Signal strength with hysteresis
RN antenna gain towards UT	7dBi	Handover	Hard handover
RN No. sectors	1	Handover margin	3 dB
Carrier Frequency	3.95GHz	Network synchronization	Fully Synchronized
Signal Bandwidth	100MHz	Call arrival process	Poisson arrivals
Duplexing method	TDD	User density	1464 users per km2
Manhattan Grid dimension	11x11 blocks	Simulation Steps	3Mio
Building Block Size	200m	Traffic model	full buffer
Street Width	30m	User speed	3km/h
Link Adaptation	Yes		

Table 4-4 Selected Simulation parameters for baseline simulations.

The SINR distribution of the received packets by UTs served by the RN presented in [WIN2D352] is much higher than the SINR of UTs served by the BS for the baseline scenario. This suggests that the reuse could be tightened and we study the performance impact of allowing both groups of RNs to use the whole bandwidth. This will be the reference scenario and the impact of further improvements will be presented as relative increase in average user throughput.

In the baseline deployment, the RNs are only one block away from the BS. Thus, the UTs between the BS and the RN can easily be served by the BS. Therefore we study the performance impact of using directive antennas pointing away from the BS to serve the UTs instead of omni-directional antennas at the RNs. This requires the use of two antennas at the RN, but no second transceiver chain or additional signal processing. This increase in hardware cost is outweighed by the improvement in average user throughput of almost 24%.

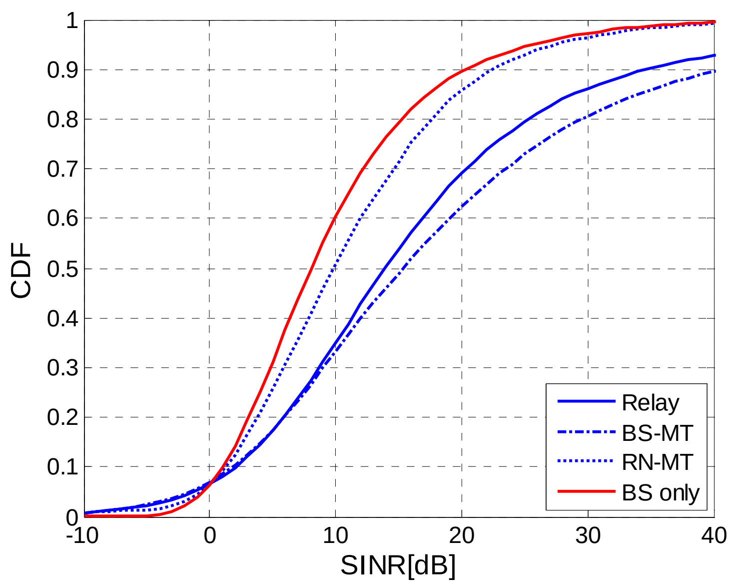

Figure 4-13: SINR distribution of the received packets for the relay deployment when RNs use the whole bandwidth compared to the same scenario without RNs.

As illustrated in Figure 4-13 the SINR of the received packets by UTs served by the RN is still much higher than the SINR in the scenario without RNs. This suggests that the reuse could be increased and we study the performance impact, when the BS is allowed to serve UTs while the RN is serving UTs. It increases the average user throughput by another 26%. However, the average user throughput is still worse than for the same deployment without RNs, denoted as BS only deployment in Table 4-5. Next, we select the optimal number of frames within the super frame where the RN is allowed to serve its UT. This number depends on the capacity of the BS-RN hop and the RN-UT hops. It is kept constant in the whole simulations and the same number is used within the whole network. Selecting the optimal number of frames for RN transmission improves the user throughput by an additional 49%. It is for further study, if the performance of the relay deployment can be improved by allowing the RNs to transmit in different frames in different relay enhanced cells.

Finally, we utilize soft frequency reuse with the power mask assignment presented in Figure 4-12 and the phased scheduling algorithm [WIN2D352], which increases the average throughput by an additional 9%. When we now compare the performance of the BS only deployment to the best relay deployment, after all the improvements, the average user throughput for the relay deployment is 28% higher than for the BS only deployment.

Deployment/design option	Relative average user throughput
Reuse 1 in frequency domain	1
Directive Antennas	1.24
BS and RN transmit at the same time	1.56
Optimal frames for RN transmission	2.33
Soft frequency reuse with phased scheduler	2.51
BS only deployment	1.96

Table 4-5 Performance impact of different deployment and preferred design options

To sum up, the reference design and reference relay deployment comprises the following changes compared to the baseline scenario presented in [WIN2D6137]: the RN transmission power is the same than the BS output power, i.e. the BS output power has been lowered, the RN is equipped with two directive antennas, the RN use the whole bandwidth to serve UT, soft frequency reuse together with the phased scheduling scheme is used for interference coordination, the BS serves UT at the same time when the RN serves UT and the amount of frames where the RN is receiving data from the BS and serving its UT is optimised based on the first and second hop capacity.

4.4.2 MIMO cooperative relaying

In the following we illustrate that a cooperative relaying scheme based on multi-user MIMO precoding can significantly increase the throughput in the metropolitan area. As an illustrative example we show results for LQ matrix decomposition based transmit precoding[2] for cooperatively served users. However, we expect similar improvements by the multi-user MIMO linear precoding techniques proposed in section 3.2.1.1.

A summary of the obtained performance results is shown in Table 4-6 where 55 BSs were simulated for the direct case without RNs and 20 BSs with 4RNs added to each BS for the relaying cases. Both the BS and the RNs were placed at the street crossings. We use the following measures to evaluate the system

[2] In the LQ transmit precoding approach the channel matrix $H \in C^{N\times M}$ is decomposed into a lower triangular matrix $L \in C^{N\times N}$ and a unitary matrix $Q \in C^{N\times M}$. Instead of directly transmitting the data vector $d \in C^{N\times 1}$, it is multiplied by the complex conjugate of Q. This ensures that the signal received by user $i \in [1; N]$ is not interfered by the transmissions dedicated to users $j > i$. Furthermore, if a dirty paper coding technique is used [Co83], [ViJiGo03], we obtain a single user channel for user i as it does not experience any interference from users $j < i$. Hence, the SINR for user i is given by $|L_{ii}|^2 p_i / \sigma^2$, where $|L_{ii}|$ is the i[th] diagonal element of L, $p_i = E\{|d_i|^2\}$ and σ^2 models the noise and interference power. A more detailed derivation of this approach as well as the constraints is given in [KaFoVa+06]. In the case of cooperative relaying the precoding is done over both the BS and the RN antennas.

performance: the 5-percentiles $\delta_{5\%}$ and $r_{5\%}$ defined by $\Pr\{\delta(\cdot,\cdot) \le \delta_{5\%}\} = 0.05$ and $\Pr\{r(\cdot,\cdot) \le r_{5\%}\} = 0.05$, respectively, the average user throughput $\overline{\delta} = E_{x,y}\delta(x, y)$ and link spectral efficiency $\overline{r} = E_{x,y} r(x, y)$ and the maximum throughput $\delta_{\max} = \max_{x,y} \delta(x, y)$.

The analysed distributed MIMO scheme does not include a quantitative overhead analysis as well as a consideration of imperfections such as imperfect channel state information. Hence, the results rather serve as upper limit and for a qualitative evaluation. The following overhead categories can be identified (exemplified using the DL):

- Before BS and RN can cooperatively transmit the BS needs to transmit the data for the cooperative transmission to the RN. This overhead has been taken into account in the simulations and it is the same overhead as in a single-path relaying system with the difference that the data must be transmitted twice by the BS whereas in a single-path relaying protocol the BS is only forced to transmit it once. On the other hand we can assume a BS-RN link of high quality and hence only few resources are necessary for the additional transmission. Furthermore, the cooperative transmission of BS and RN offers significant improvements in terms of intra-cell interference management especially in those areas where BS-UT and RN-UT are of similar quality where in single-path relaying the performance is anyway limited due to the BS interference.
- In a cooperative transmission the RN must additionally transmit the CSI for its RN-UT links to the BS as well as vice versa such that a distributed precoding can be performed. The additional CSI which needs to be exchanged is increased by a factor of $A*(M_{BS} + M_{RN})*N_{UT}$. The pre-factor A highly depends on the quantisation quality and technique as well as on the robustness of the precoding (which is a topic discussed in the context of MIMO-broadcast channel). Furthermore, as distributed MIMO is only applied to slowly moving objects we might assume a high coherence time and bandwidth which further decreases the necessary overhead.
- Finally, we must consider the additional distributed precoding operation which has to be performed at the RN and BS. As this step is a standard procedure used in usual MIMO system, this overhead can be neglected.

Obviously, only the second point represents serious additional overhead which has not been considered in our simulations but should be included while comparing single-path and cooperative relaying. Nonetheless, the question for a quantitative measure of this overhead highly depends on the quantisation quality as well as time and frequency coherence of the channel and can not be answered in general. Therefore, we present here upper limits on the expected performance which already give a qualitative impression how and where cooperative relaying is able to provide significant improvements to the system's performance.

.Scenario	Protocol	$\delta_{5\%}$	$\overline{\delta}$	$\delta_{\max}$
BS and RN placed at crossings	Direct	0.24	3.42	13.76
	Single-Path Relaying (in-band / out-of-band)	1.12 / 1.84	4.99 / 6.14	24.35 / 24.41
	Cooperative Relaying (in-band / out-of-band)	3.23 / 5.45	7.64 / 9.93	40.19 / 42.46

Table 4-6Numerical results for the link throughput in the urban coverage and dense urban scenario; all values are given in Mbit/s

4.4.2.1 Benefits of REC

The increased $\delta_{5\%}$ in Table 4-6 shows that relaying reduces the number of users with low throughput. When comparing cooperative relaying to direct transmission the 5-percentiles of the user throughput CDF are increased 13-fold for the metropolitan area scenario. Cooperative relaying can almost triple the 5-percentile of the user throughput CDF compared to single-path relaying. Also the maximum as well as average throughput is significantly increased by both single-path and cooperative relaying strategies. Under the taken assumptions and scenario set-up, cooperative relaying more than doubles the average user throughput compared to direct transmission. Cooperative relaying offers the potential to further improve the gain of single-path by more than 50%.

Similarly, in a REC the number of users with low link spectral efficiency is decreased (see Figure 4-14) and the average link spectral efficiency is increased. Furthermore, consider Figure 4-14 which shows the CDF of link throughput and link spectral efficiency. The usage of link spectral efficiency might be unusual to evaluate the system level performance, but it allows for interesting conclusions. In particular the CDF of the link spectral efficiency can give some intuition on the sensitivity of the results to the utilised scheduling scheme. For example the potential scheduling gain is low for a steep CDF, whereas it is high for a flat CDF. Consider the link spectral efficiency CDF curves of single-path and cooperative relaying. One can see that the single-path relaying CDF is much flatter, i.e. the potential scheduling gain is higher than for cooperative relaying. The equal resource scheduler, used in our simulations, cannot really exploit the flat link spectral efficiency CDF. A more aggressive scheduling strategy, e.g. maximum throughput scheduler, could provide more significant performance improvements for single path relaying than for cooperative relaying. Nevertheless, we can state that the application of cooperative relaying can add further gains to RN based deployment.

Figure 4-14 indicates that the link spectral efficiency of 50% of the links is higher for single-path relaying than for cooperative relaying. This can be explained by the fact that in the case of cooperative relaying the precoding is done over both the BS and the RN antennas. Thus, more data streams are transmitted to more users simultaneously. Therefore the SINR of a single stream and the link spectral efficiency is reduced. However, the overall throughput is still higher.

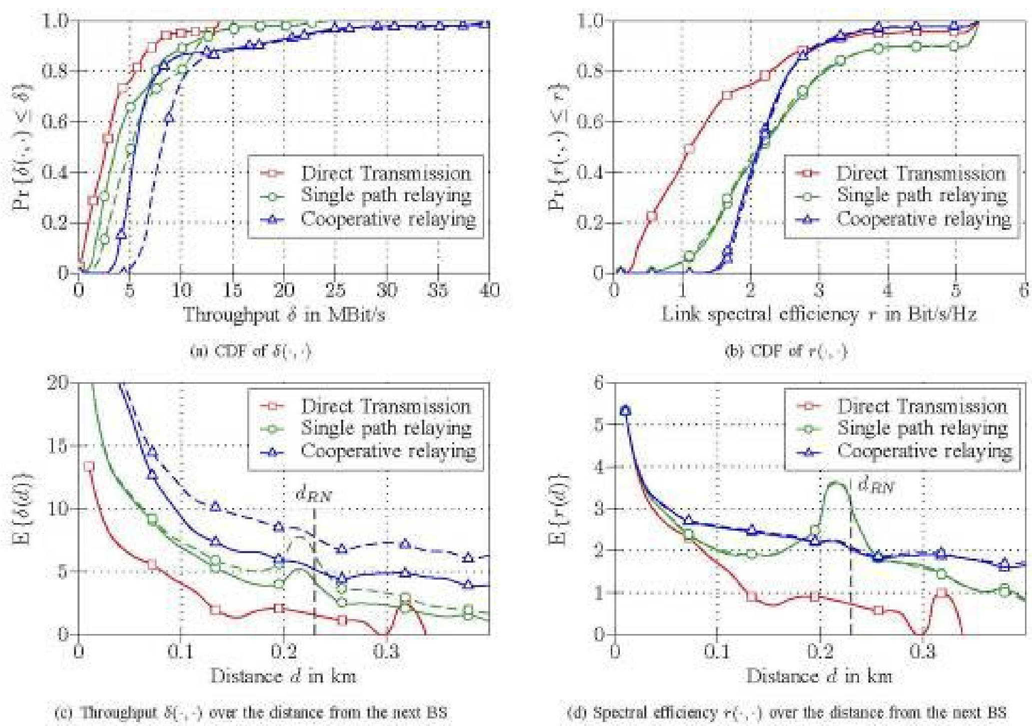

Figure 4-14: Throughput and link spectral efficiency for the metropolitan area scenario. Solid lines are used to show results for a REC with realistic feeder links and dashed lines for the results if neither in-band resources are used for the BS-RN link nor any constraints are applied on it.

We can further observe that due to the half-duplex constraint and the in-band relaying the performance is significantly reduced. Without these constraints the average throughput could be increased by another 25 to 50%. Furthermore, we can see that cooperative relaying provides the means for further performance improvement on top of single-path relaying. It can be assumed that with the more advanced RRM schemes presented for example in [WIN2D352], the performance difference between single-path and cooperative relaying will further decrease or even vanish in certain cell areas (especially in those areas where the BS-UT is significantly worse compared to the RN-UT link). On the other hand, cooperative relaying promises to be superior in those areas where the BS-UT and RN-UT links are of comparable quality (in terms of SNR). Combining both, single-path and cooperative relaying, by adaptively using the most promising protocol will likely prove to be the preferable strategy.

4.4.2.2 Description of reference method used for comparison

To be independent of the choice of space-time processing technique in the reference method, it is based on the theoretically achievable maximum sum rate under sum power constraint when channel knowledge is available at the transmitter (aka Dirty Paper Code Bound). The approach is an updated version of the one used in [WIN2D341] and published in [FKKH07]. The DPC bound rates are computed using the frequency flat, iterative uplink algorithm of [JIND05]. As a consequence, the study is limited to one subcarrier and the possibility of using OFDMA (which is given in the basic design of [WIN2D351]) cannot be investigated. This is due to the fact that in the literature no such algorithm was available when this research was started to treat also the space frequency power loading problem at the same time. A simplified frame structure is used such that one instance of the DPC algorithm is run per drop of the channel. Doppler effect is not analysed.

When a system with MU-MIMO and relaying is considered, a centralised scheduler needs to assign the users to the transmitters. A genie-like scheduler is used and the RNs have a data buffer. The simulation steps for the reference performance are as follows:

1. Compute the DPC bound rates for all users when served by each one of the BSs and RNs separately, assuming independent single cell systems with one transmitter only. In the odd time slots RNs do not transmit but are also users (receivers). In the even time slots, the RNs act as BSs.
2. Genie-like scheduler knowing all achievable rates: Decide on the assignment of users to RNs and BSs based on the achievable DPC rates from step 1 (no interference considered in this step, suboptimal).
3. Recompute DPC covariance matrices for the newly assigned groups (second run of DPC algorithm required).
4. Perform uplink-downlink conversion of the newly computed covariance matrices as in [VJG03].
5. Compute downlink rates for the entire system WITH interference (all transmitters) using the downlink DPC covariance matrices from step 4 and taking into account a buffer level at the RNs: The role of the RNs depends on the time slot number. When the RNs receive, they fill up their buffer. When they transmit, the achievable rates of the UTs assigned to RNs are limited by a user specific buffer level of the serving RN (see the ProSched description in section 3.4.3 for how the buffer is implemented).

4.4.2.3 Discussion

The ProSched algorithm exists in variations with different complexity. The version simulated here uses rank one reduced bases of the users' subspaces to compute their nullspace projection matrices, which was originally meant for complexity reduction. In this setting, however, it allows to reduce considerably the overhead data to be transmitted to the central intelligence. This kind of overhead was not estimated, but is certainly present in both the reference method and the more practical method.

The precoding scheme used together with ProSched is SMMSE with dominant eigenmode transmission [WIN2D341], which was the baseline scheme proposed in [WIN2D6131]. We also show the performance of the proposed reference method taking into account the resource sharing between two groups of RNs as proposed in [WIN2D351] and implemented in time direction. Figure 4-15 shows the probability of exceeding a certain total system throughput for ProSched with interference avoidance using SMMSE dominant eigenmode transmission versus a reference based on the theoretically achievable maximum sum rate and a centralized genie scheduler without interference avoidance. The total surface was around 2 km^2. It can be seen that the proposed scheduler suffers a slight drawback in peak throughput (due to the sub optimality of the precoder), but increases the stability in a wide range of the graph. The absolute figures are, however, of limited value: Overhead present for both methods will reduce them significantly, but less for the ProSched method as said above. And both schemes will suffer from outdated and erroneous channel state information in the same way, since they are based on linear precoding.

It can be seen in Figure 4-15 that the proposed low complexity scheduler performing joint interference avoidance together with low complex precoders increases the probability of achieving high rates in a wide range of the graph but suffers a slight drawback in peak throughput, likely due to the sub optimality of the precoder. Note that precoding is done separately for each transmitter but that the presented coordinated scheduler takes into account the predicted interference which depends on the selection of the users. The interference generated is different for each possible user assignment requiring different precoding matrices at each transmitter. However, the ProSched interference prediction scheduling requires no additional computation of any precoding matrices during the testing of combinations. The reference performance is based on the maximum rates that each transmitter can theoretically achieve when serving its assigned users as well as a genie scheduler who does not perform interference avoidance. To that extend the gain that is visible stems from interference avoidance.

Note that an even higher gain can be expected in a highly populated scenario (the number of users simulated was limited due to complexity) due to higher selection diversity. Furthermore, in an OFDM system, more degrees of freedom are available for interference avoidance.

Furthermore it was observed that non-intelligent interference avoidance in the form of time-sharing (i.e., forming two RN groups in time) may reduce the achievable rates (dashed curve). This conclusion may also change when the number of users in the system is increased.

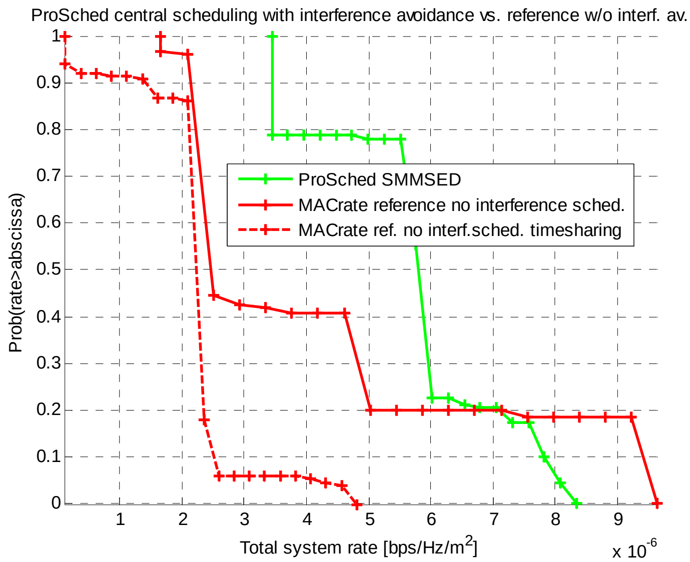

Figure 4-15: Performance of ProSched with interference avoidance using SMMSE dominant eigenmode transmission.

4.4.3 Cost analysis for relay deployments in the metropolitan area CG scenario

The main motivation to deploy fixed wireless relays in a wireless communication system is to save costs while achieving a similar service level or coverage than with a base station only deployment. A cost methodology based on indifference or iso-performance curves was introduced in [WIN2D351], enabling a trade-off between the number of relays and the number of base stations in a network. Thus, the least-cost network configuration could be determined.

Unfortunately in the MA CG scenario the possible positions of the radio access points are limited. Therefore the BS and RN density cannot be varied by the required granularity to perform an indifference curve analysis. However we can compare the cost and the performance of selected RN deployments to selected BS only deployments. In Section 4.4.1 we present a cost comparison for BS only and relay deployments using a real cartography of Madrid and in Section 4.4.3.3 we compare the performance and cost of selected BS only and relay deployments in the Manhattan grid.

4.4.3.1 Simulations in real dense urban scenario

The purpose of these simulations is to validate the relaying concept from a cost perspective in a particular dense urban scenario (real cartography of Madrid), comparing different kind of deployments, with and without relay nodes, but with the same or similar performance from a capacity density and coverage percentage points of view. The simulations only contemplate the downlink direction and they are the continuation of the ones carried out in [WIN2D352]. They are system level class III simulations (static or quasi-static behaviour of the system) based on a 3D ray-tracing model for the estimation of the SINR over a real cartography of Madrid city. The preliminary results indicated that the total cell capacity decreased when we included relay nodes, but then the service area enlarged. The reason for the reduction of the capacity was the inefficient resources partitioning used, and so it was decided to implement a strategic more efficient in order to reduced the wasted resources.

It is important to note that these simulations are focused in the comparison of traditional and relay-based deployments from a cost analysis viewpoint, and then not any protocol aspect has been considered, assuming a correct operation of all protocol functions, concentrating the analysis in the performance of the deployment exclusively from a radio propagation perspective.

The parameters used in the simulations as well as the procedures and methodology are described in the Annex A.2 and section 2.3 of [WIN2D352] and in section 4.4.1 of [WIN2D3.5.3]. Table 4-7 presents the main simulation parameters, which are based on the baseline assumptions outlined in [WIN2D6137] for the metropolitan area scenario.

Parameter	Value	Comments
Duplexing scheme and asymmetry	TDD (1:1)	Only DL
Carrier central frequency (DL)	3925 MHz and 3975 MHz	Frequency reuse of 2
Channel bandwidth	50 MHz per sector	
BS location and height	Below rooftop at 10 m from the street floor	
Maximum transmit power per sector	37 dBm (5.012 W)	
Number of antennas per sector and type	1 antenna with 14dBi elevation gain and 65º beamwidth	Similar radiation pattern to the proposed in WINNER baseline assumptions
RN location and height	Below rooftop at 10 m from the street floor	
Inter site distance of BSs in the same street	Around 600 m in vertical streets and 700 m in horizontal streets	In order to avoid either the crossroads or streets corners
Number of sectors per BS site	2	
UT height	1.5 m	
Elevation antenna gain for UT	0 dBi	
Receiver noise figure for UT	7 dB	
RN location and height	Below rooftop at 10 m from the street floor	
Maximum transmit power per RN	30 dBm (1 W)	
Number of antennas per RN and type	1 antenna with omni-directional pattern	
Elevation antenna gain for RN	7 dBi	
Receiver noise figure for RN	5 dB	
Distance between the sector of a BS and its associated RN	Around 300 m	In order to avoid either the crossroads or streets corners
Target User Throughput	2Mb/s	
User Density	1600UT/ km2	static users, slightly more than in a typical hot spot scenario
Resource partitioning	Iterative to balance the resources used on BS-RN and RN-UT links	

Table 4-7 Simulation parameters used in real, dense urban scenario

From a cost analysis perspective it is important to note that the micro BSs used in the simulations are composed by two sectors, each one with its antenna and equipment but sharing of course the site acquisition and transmission line costs.

As Table 4-8 shows, we chose deployments, base stations only and relay based, that achieve the same performance and for at least five different configurations (one for BSs only and four for relay based) in order to apply the indifference curve methodology, and so to get the least cost deployment in terms of cost ratio between base station and relay node. Unfortunately due to the limitations of our particular scenario (area of 1300 m per 1300 m with irregular streets and size of blocks), the number of radio access points as well as their locations were restricted to certain values so that it was impossible to obtain enough points (BSs and RNs configurations) with the same performance for delineating one iso-performance curve. In any case there were two deployments with the same performance, one using only

BSs and the other one replacing two sectors by four relays. For the same reason and in order to avoid the location of RAPs near to the corners, the separation between adjacent BSs was 600 m in the horizontal streets and 700 m in the vertical streets. For the RECs the distance between the BS and its associated RNs was around 300 m.

Configuration	Number of BSs	BSs density (Km2)	Number of sectors	Sectors density (Km2)	Number of RNs	RNs density (Km2)
1 (BSs only)	32	18.93	64	37.87	-	-
2 (relay based)	30	17.75	60	35.50	2	1.18
3 (relay based)	30	17.75	60	35.50	4	2.37
4 (relay based)	28	16.57	56	33.14	8	4.73
5 (relay based)	31	18.34	62	36.69	4	2.37

Table 4-8 Different configurations used in the simulations for relaying concept validation

4.4.3.2 Simulation Results

Table 4-9 summarises the results of our simulations highlighting the two configurations: one BSs only, and another one relay based, which showed the same capacity density and coverage. As we can see the indoor coverage detected was very poor in all the cases due to the high frequencies used by the RAPs whereas the coverage along the streets was more than 93 % for the best deployments. The spectral efficiency of the users was approximately in the range from 0.2 to 4 bps/Hz, being lower than 1 bps/Hz for 40 % of the served users (average of all RAPs included in the deployment).

Configuration	**Total number of active users @ 2 Mbps**	**Density capacity (Mbps/Km^2)**	**Total coverage (%)**	**Outdoors coverage (%)**	**Indoors coverage (%)**
1 (64 sectors)	1925	2278.11	71.19	93.12	60.47
2	1850	2189.94	68.44	89.49	58.15
3	1866	2208.88	69.03	90.26	58.64
4	1824	2159.17	67.47	88.23	57.35
5 (62 sectors + 4 RNs)	1930	2284.62	71.39	93.36	60.62

Table 4-9 Performance in terms of density capacity and service area showed by each of the configurations used in the simulation for relaying concept validation

Figure 4-16 shows the service area for each of the two deployments (BSs only and relay based), which presented the same performance in terms of coverage and capacity density. Note that in spite of the practically total coverage along the streets obtained in both deployments, there are some outage zones mainly in the outer part of the scenario, causing a noticeable reduction in the total coverage of the deployment. Also, it was observed that there are some internal zones with a very poor spectral efficiency. These are probably due to the particular characteristics of the surroundings buildings (height and materials). The only way to avoid these irregularities would be to carry out a detailed network planning (exact orientation and location of antennas), taking into account the special features of these zones.

Concerning the RECs (bi-sector BS with two relays) included in the relay based deployment, it is important to comment that the REC was approximately 1.6 times more efficient than a simple BS, that is, while a BS gives service to 50 users, the REC is able to serve at 80 users.

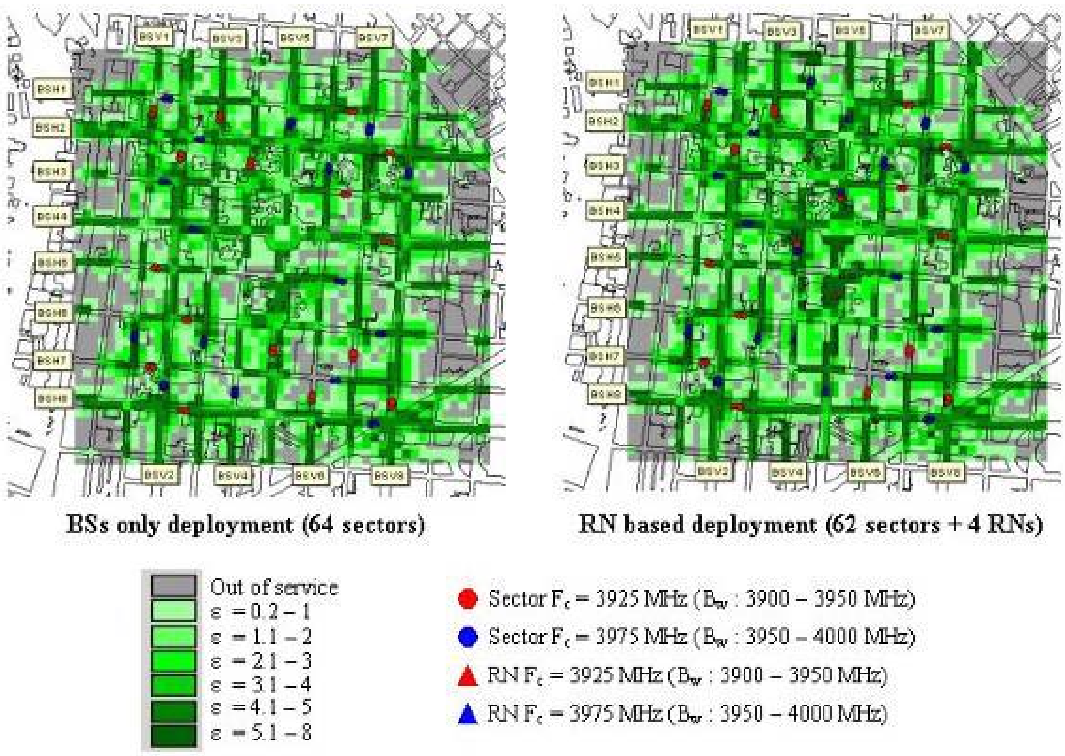

Figure 4-16: Comparison of the two deployments, BSs only and relay based, which exhibited the same performance in terms of capacity density and service area. The grey zones represent outage areas (users without service) due to a very bad SINR. The total service coverage area is 71.19 % and 71.39 % for the BSs only and relay based deployment respectively, assuming a target user throughput of 2 Mbps. The capacity density obtained in each case is 2278.11 (BSs only) and 2284.62 (relay based) Mbps/Km^2

The final objective of our simulations is to investigate whether a relay-based deployment is beneficial from a network cost point of view in the particular metropolitan scenario used. As the results show, there was a relay based configuration with the same performance than traditional BS only deployment. Thus we have demonstrated that using an efficient resource-partitioning scheme, it is possible to obtain a deployment exchanging BSs per RNs with the same network performance. The cost efficiency between the BS only deployment and BS with relays depends on the cost ratio between BS and RN.

Regarding this topic and according to available literature [JFK+04], and preliminary estimations performed in WINNER project [WIN2D61313], the Table 4-10 provides some examples of CAPEX and OPEX for different RAPs (micro base station, pico base station and relay node). The relay of this table has a transmit power of 33 dBm, which is not exactly the same as the one used in our simulations, where the maximum transmit power used for RNs was 30 dBm. Further, when assuming that the RN could for example be mounted on lamp posts, the cost of RN will likely be close to the costs of a pico BS. On the other hand it is important to remark that the cost figures showed in this table are only cost examples based on estimations, and therefore the real cost could definitely vary depending on the deployment scenario and should be understood only as a demonstration basis. The OPEX costs are represented by their net present value (assuming a lifetime of ten years and a discount rate of 6%), and in this way the CAPEX and OPEX can be combined, for comparison purposes of different RAPs. According to this approach the total costs of a micro BS and a RN (output power of 33 dBm) are 40.79 and 26.6 K€ respectively, yielding a BS/RN cost ratio around 1.5. When comparing the total costs of a micro BS to the costs of a pico BS without the cost for a fixed line connection, the ratio is 6.8.

Cost Element	**Unitary Cost for CAPEX or Net Present Value for OPEX (K€)**	**Cost Type / Comments**
Micro BS Equipment	5	CAPEX
2x2 Micro BS Equipment	7.5	CAPEX / small footprint
Micro BS Site Acquisition and	6	CAPEX / Small footprint

Deployment		
Micro Fixed Line Connection	0.05	CAPEX / Connection to mass-market ADSL line
Micro BS Site Rent, Maintenance and Power	23.4	OPEX / no back-up batteries
Micro/Pico BS Fixed line Connection Rent	6.24	OPEX
Pico BS Equipment	2	CAPEX
Pico BS Acquisition and Deployment	0.1	CAPEX
Pico BS Site Rent Maintenance and Power	3.9	OPEX
RN Equipment	7	CAPEX / Small footprint and not backhaul (max. transmit power of 33 dBm)
RN Site Acquisition and Deployment	4	CAPEX
RN Site Rent, Maintenance and Power	15.6	OPEX / no back-up batteries

Table 4-10 CAPEX and OPEX cost elements example for different RAPs

Conclusion and discussion

The conclusion of the simulations for the relaying concept validation in a metropolitan area scenario is clear. In the simulation scenario, inclusion of relays would be beneficial from network cost point of view whenever the total cost of a relay used in the simulations will be lower than half of the cost of a sector included in the micro BS. Of course we should include all costs (CAPEX and OPEX) and analyse the special features of the scenario (for example availability of transmission lines and prices) in order to make a proper evaluation for deciding the best economical option.

Finally, although we have estimated the cost ratio between micro BS with two sectors and RN to be near to 4 (coming from the relay-based configuration including RECs in two streets) for making a decision of what deployment to use, we could extrapolate the results at the whole of the deployment, using RECs in all the streets (1.6 times more efficient than a BS), so that the BS/RN costs ratio would be around 3 instead of 4.

4.4.3.3 Cost/performance comparison for selected relay and BS only deployments

Unfortunately in the MA CG scenario the possible positions of the RAPs are limited (in streets or at street crossings). Therefore the BS and RN density cannot be varied by the required granularity to perform an indifference curve analysis. However we can compare the cost and the performance of selected RN deployments to selected BS only deployments. In this comparison we will focus on deployments with both BS and RN in the streets.

The deployment patterns of the selected BS only deployments are illustrated in Figure 4-17 to Figure 4-19.. The numbers in the brackets denote the amount of BS sectors in the whole simulated Manhattan grid and will be used as an identifier of the scenarios in the analysis. Figure 4-20 and Figure 4-21 illustrate the deployment pattern of selected relay deployments, where RNs have been added to the BS only deployments presented in Figure 4-17. The RN associate with the closest BS and each BS sector has one associated RN, except for the scenario shown in Figure 4-20 where only one of the two BS sectors has an associated RN.

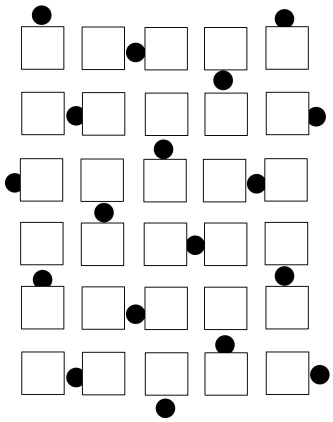

Figure 4-17: BS only deployment with 2 sectors per BS (144BS).

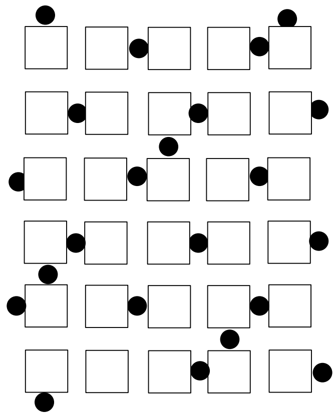

Figure 4-18: BS only deployment with 2 sectors per BS (178BS).

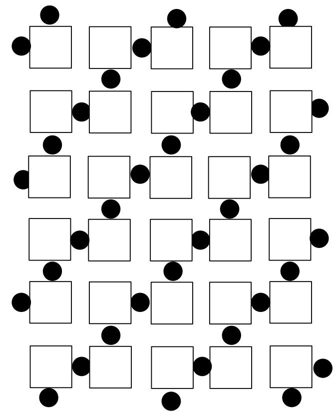

Figure 4-19: BS only deployment in street with 2 sectors per BS (286BS).

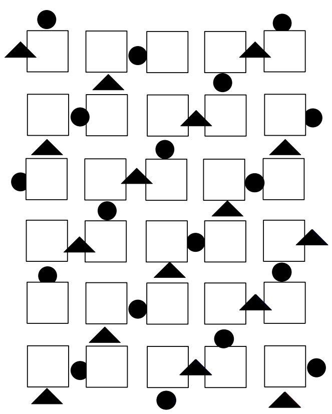

Figure 4-20: Relay deployment in with 1RN for BS sector pointing down or to the right (144BS 72RN).

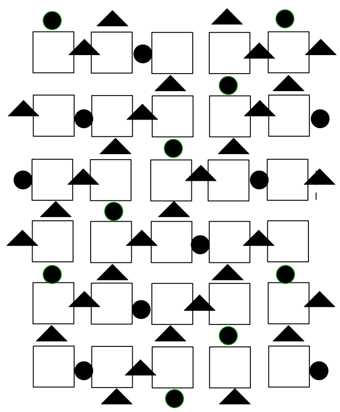

Figure 4-21: Relay deployment with 1 RN for each BS sector (144BS 144RN).

For the comparison of the different deployments we use the cost examples provided in [WIN2D6136]. The capital expenditure (CAPEX) of the RN has been assumed to be comparable to a pico BS (2.1k€), for the 2 sector BS in the street we assume the cost of a 2x2 micro BS (13.5k€). Similarly we assume the same operational expenditure (OPEX) for the RN than for a pico BS which sums up to 3.9k€ over 10 years excluding the cost for the backhaul connection. The OPEX for the micro BS in the street include additionally the costs of the fixed line connections and the overall OPEX sum up to 29.5k€ over 10 years. Thus, the costs over 10 years are assumed to be 6k€ per RN and 43.2k€ for the micro BS, respectively.

We compared the different deployment options in dynamic system simulations using the same simulation parameters as described in Section 4.4.1, except that the BS power is now 37dBm per sector instead of 30dBm. The user density is kept constant at 418 UT/km^2 in all simulations and all UT are located indoors. The performance indicators are only evaluated from the monitored center cells. The amount of monitored cells has been chosen such to get a comparable monitored area for each scenario. It varies between four cells for the scenario illustrated in Figure 4-17 to 8 cells for the scenario presented in Figure 4-19. To get comparable results, the throughput and the costs have been normalised by the coverage area of the monitored center cells.

We use the resource partitioning and deployment options described in Section 4.4.1 to optimise the performance of each deployment. First, we run simulations with and without directive antennas at the RN. Further, we test whether a scenario with RN and BS transmitting at the same time outperforms a scenario where RN and BS transmit in different time slots. Finally, we also find the optimal number of frames in which the RN should be allowed to transmit. After exploring all these resource partitioning options for each scenario, we pick the best performing combination and use it for the comparison of the different scenarios.

The outcome of this comparison is illustrated in Table 4-11. The scenarios are sorted by their average area throughput starting with the scenario that has the highest average throughput per km^2. To select the most cost efficient deployment option for a given target performance, the cheapest deployment option that can meet the performance target has to be chosen. For example when an area throughput of 150 $MByte/s/km^2$ is targeted, the relay deployment in the street with a single RN for each 72 BS site (144 sectors) is the most cost efficient deployment. The next best BS only deployment has about 20% higher costs per km^2 and year.

No.Sectors No.RN	286	178	144 72	144 144	144
Average Throughput in MB/s/km2	326	173	173	172	129
Cost in k€/km2/year	80	50	46	52	40

Table 4-11 Scenario comparison: the average throughput and the cost have been normalized per area

The comparison of the different deployment scenarios illustrates that relay deployments can be more cost efficient than BS only deployments. If the target throughput is for example 150 $MB/s/km^2$, the RN deployment is 10% cheaper than the next BS only deployment that can meet this target. The cost figures used in the comparison take both capital and operational expenditures over 10 years into account and results in less than one sixth of the costs for a RN than for a 2 sector micro BS. The cost advantage of the relay deployment disappears for a RN/BS cost ratio of 0.25 or higher. However, as illustrated in the previous sections, the performance of the relay deployment can be further improved for example by cooperative relaying or soft frequency reuse. Thus, we expect that the relay deployments will be cost efficient also for higher RN/BS cost ratios. Further, the results in Table 4-11also indicate that dense BS only deployments are preferable if very high throughput is required.

4.5 Influence of Scheduling Strategies on the Cell Throughput

4.5.1 Performance of the adaptive OFDMA downlink transmission in the Metropolitan Area scenario, SISO transmission

To evaluate the performance of the adaptive OFDMA downlink transmission, system-level simulations have been performed with different scheduling algorithms. These investigations complement other investigations in the other Concept Group deliverables [WIN2D61310] and [WIN2D61312] , which have used a few schedulers to improve comparability of the results, in particular the Score-based scheduler that was recommended in [WIN2D6137]. The results illustrate the influence of scheduling algorithm choices on the cell throughput distribution and the sensitivity of the results to this choice.

The considered system parameters (except for the choice of scheduler) are specified in [WIN2D6137], and the interference model has been specified according to the analysis presented in Appendix 7.1. The codeword length for each user was 288 bits, with LDPC coding employed (mother rate ½) [WIN2D6137]. The target codeword error rate was 0.1. The overhead considered includes pilot overhead and the duplexing guard intervals overhead. Two different scenarios were investigated:

- 8 users scheduled during each superframe out of 40 users distributed uniformly in the cell;
- 8 users scheduled during each superframe out of 20 users distributed uniformly in the cell.

The aim of the simulation was to achieve the satisfied user criterion with the proposed system setup (95% of all users achieve the throughput of at least 2 Mbit/s). The following scheduling algorithms have been considered:

- Round Robin (RR);
- Fair Time sharing/Maximum SNR (FT/MaxSNR);
- Maximum SNR (MaxSNR);
- Fair Rate (FR1);
- Fair Rate without optimum search (FR2);
- Fair Time sharing/Proportional Fair (FT/PF);
- Proportional Fair (PF) [Bon04];
- Fair Time sharing/Score Based (FT/SB);
- Score Based (SB) [Bon04].

Figure 4-22 and Figure 4-23 present the cumulative distribution function of the users' throughput. Figure 4-22 presents the CDF of the users throughput achieved when 40 users are distributed within a cell. It can be clearly observed that the required satisfied user criterion cannot be achieved for any of the selected scheduling algorithms in this case in which single-antenna transmission is used. The best performance was achieved by the Proportional Fair scheduler. However, even with this algorithm, more than 20% of the users achieve average throughput lower than 2 Mbit/s.

For 20 users distributed within the cell, the satisfied user criterion can be fulfilled for selected scheduling algorithms.Figure 4-23 presents the cumulative distribution function of users' throughput for this case. It can be observed that for both Fair Rate algorithms approximately 95% of the users have the throughput over 2 Mbit/s. Also for both Proportional Fair algorithms the satisfied user criterion is almost achieved with more than 90% of the users "satisfied".

The advantage of the Proportional Fair scheduling over other considered algorithms is the high average throughput achieved by the users and high total cell capacity, as presented in Table 4-12 and Table 4-13 for 40 and 20 users distributed respectively. It outperforms Fair Rate scheduling in terms of achieved throughput and it outperforms the Score Based algorithm in terms of the percent of the "satisfied" users.

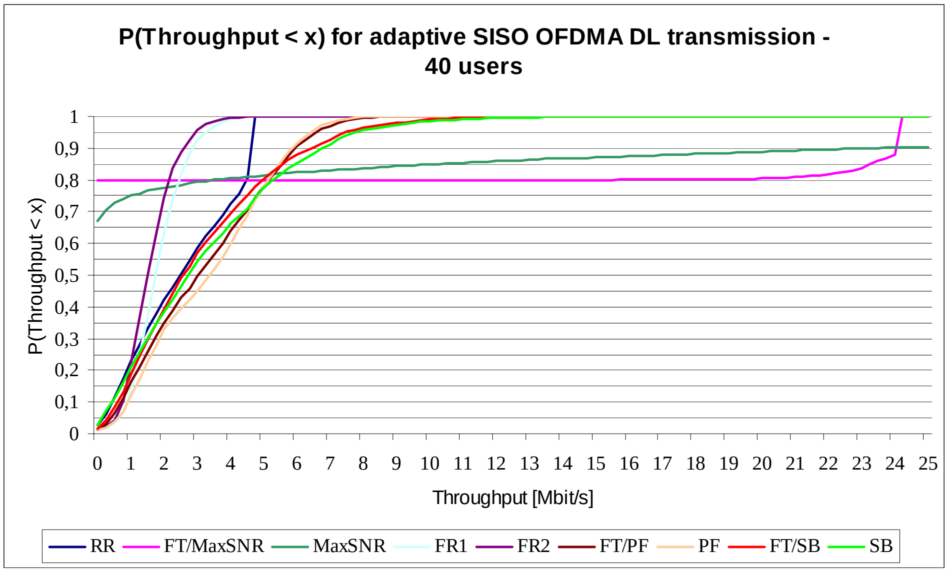

Figure 4-22: Probability to have a throughput lower than 'x' for adaptive OFDMA transmission in case of 40 users distributed within a cell.

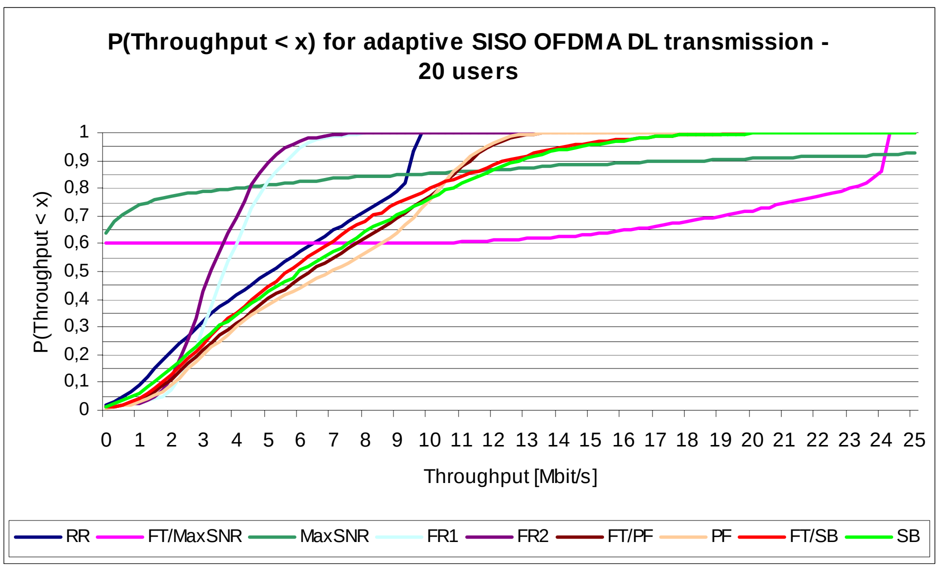

Figure 4-23: Probability to have a throughput lower than 'x' for adaptive OFDMA transmission in case of 20 users distributed within a cell.

Distance between BS and UT [m]	RR	FT/ maxSNR	MaxSNR	FR1	FR2	FT/PF	PF	FT/SB	SB
50	4,82	24,32	30,37	1,92	1,79	5,92	4,86	4,08	5,12
100	4,73	20,40	17,24	1,90	1,83	5,59	5,10	4,56	4,84
150	4,06	8,05	7,06	2,03	1,84	4,83	4,86	4,37	4,73
200	3,38	3,97	3,92	2,05	1,80	4,19	4,54	4,14	4,38
250	3,30	2,06	2,55	2,20	1,84	4,01	4,38	4,22	4,42
300	2,69	0,69	1,08	2,16	1,84	3,34	3,87	3,66	3,71
350	2,08	0,35	0,51	2,12	1,82	2,60	2,91	2,91	2,71
400	1,20	0,06	0,10	1,71	1,47	1,64	1,83	1,79	1,76
450	0,90	0,06	0,10	1,49	1,31	1,28	1,48	1,50	1,45
500	1,04	0,00	0,01	1,72	1,49	1,42	1,58	1,63	1,65
Total cell capacity	106,71	189,49	190,50	77,10	67,92	132,73	137,86	128,83	134,50

Table 4-12 Average user throughput in Mbit/s depending on the distance to the BS for selected scheduling algorithms in case of 40 users distributed within a cell

Distance between BS and UT [m]	RR	FT/ maxSNR	MaxSNR	FR1	FR2	FT/PF	PF	FT/SB	SB
50	9,64	24,33	64,61	3,74	3,74	11,17	10,82	9,99	10,84
100	9,47	23,65	33,60	3,86	3,81	11,08	10,85	9,30	9,76
150	8,27	17,84	17,40	4,06	3,81	9,68	9,93	8,57	9,13
200	6,96	12,55	6,88	4,22	3,76	8,42	8,96	8,58	8,96
250	6,58	9,88	5,00	4,40	3,85	7,94	8,54	8,80	8,62
300	5,35	5,17	2,84	4,42	3,82	6,70	7,11	7,29	7,45
350	4,27	2,98	1,45	4,30	3,73	5,48	5,91	5,97	6,27
400	2,66	1,07	0,45	3,36	2,99	3,66	3,90	3,92	4,03
450	1,92	0,00	0,07	3,04	2,76	2,82	2,99	2,98	3,02
500	2,13	0,20	0,10	3,37	3,06	3,09	3,26	3,29	3,28
Total cell capacity	106,91	170,49	190,09	77,25	69,98	132,00	137,08	130,74	135,37

Table 4-13 Average user throughput in Mbit/s depending on the distance to the BS for selected scheduling algorithms in case of 20 users distributed within a cell

4.5.2 Performance of the adaptive OFDMA downlink transmission in the Metropolitan Area scenario, MIMO transmission

Further investigation of the adaptive OFDMA DL transmission has been performed using the MIMO transmission scheme. A simple MIMO beamforming strategy has been employed using 4 transmit antennas and 2 receive antennas. The considered system setup and investigated scheduling algorithms were the same as for SISO transmission. In each superframe 8 users were scheduled at a time of the total 40 users distributed uniformly in the cell. The aim of the simulation was to achieve the satisfied user criterion with the proposed system setup (95% of all users achieve the throughput of at least 2 Mbit/s).

In Figure 4-24, the CDF of the users' throughput achieved when 40 users are distributed within a cell is shown. The satisfied user criterion may be achieved using the Fair Rate scheduling strategy. However the disadvantage of this approach is the low spectral efficiency of the system. The optimal solution is the Proportional Fair scheduling strategy, as more than 90% of the users achieve throughput higher than 2 Mbit/s. Also the spectral efficiency of the system is high when using the Proportional Fair scheduler.

When considering MIMO transmission also simple Round Robin strategy yields good results. Almost 90% of the users achieve throughput of 2 Mbit/s or higher, however it is still outperformed by the Proportional Fair scheduler.

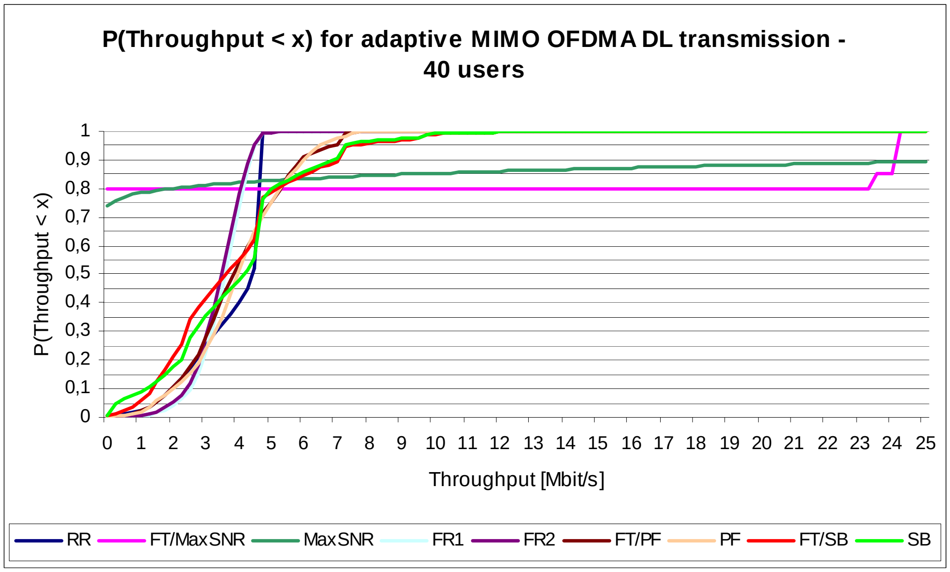

Figure 4-24: Probability to have a throughput lower than 'x' for adaptive MIMO OFDMA transmission in case of 40 users distributed within a cell.

The advantage of the Proportional Fair scheduling over other considered algorithms is the high average throughput achieved by the users and high total cell capacity, as presented in Table 4-14 It outperforms Round Robin scheduling in terms of achieved throughput. Hence, the Proportional Fair scheduling strategy is the optimal one.

Distance between BS and UT [m]	RR	FT/ maxSNR	MaxSNR	FR1	FR2	FT/PF	PF	FT/SB	SB
50	4,83	23,96	30,81	3,66	3,66	4,70	4,36	4,04	4,48
100	4,82	20,22	17,68	3,72	3,71	4,72	4,29	3,99	4,43
150	4,59	8,87	7,03	3,71	3,69	4,63	4,25	3,97	4,44
200	4,50	3,67	4,07	3,62	3,58	4,72	4,48	4,08	4,32
250	4,64	1,99	2,46	3,78	3,71	4,64	4,64	4,28	4,49
300	4,38	0,37	1,05	3,75	3,64	4,51	4,85	4,39	4,48
350	3,91	0,19	0,48	3,74	3,58	4,19	4,64	4,27	4,30
400	2,90	0,06	0,09	3,41	3,23	3,11	3,54	3,60	3,42
450	2,51	0,05	0,11	3,29	3,12	2,79	3,12	3,34	3,04
500	2,76	0,00	0,01	3,47	3,29	3,02	3,42	3,64	3,30
Total cell capacity	156,73	193,00	192,98	144,42	140,57	162,15	165,09	157,65	161,64

Table 4-14 Average user throughput in Mbit/s depending on the distance to the BS for the MIMO transmission

The use of MIMO transmission scheme yields a significant increase of performance of the system, both in terms of spectral efficiency and throughput offered to users. It allows serving up to 40 users within a sector, comparing to only 20 users when considering SISO transmission. Figure 4-25 shows the improvement of ability of achieving the satisfied users criterion when using MIMO transmission for selected scheduling algorithms. It can be observed that the best results in terms of achieving the satisfied user criterion are obtained for MIMO transmission when using the Fair Rate or Proportional Fair scheduling.

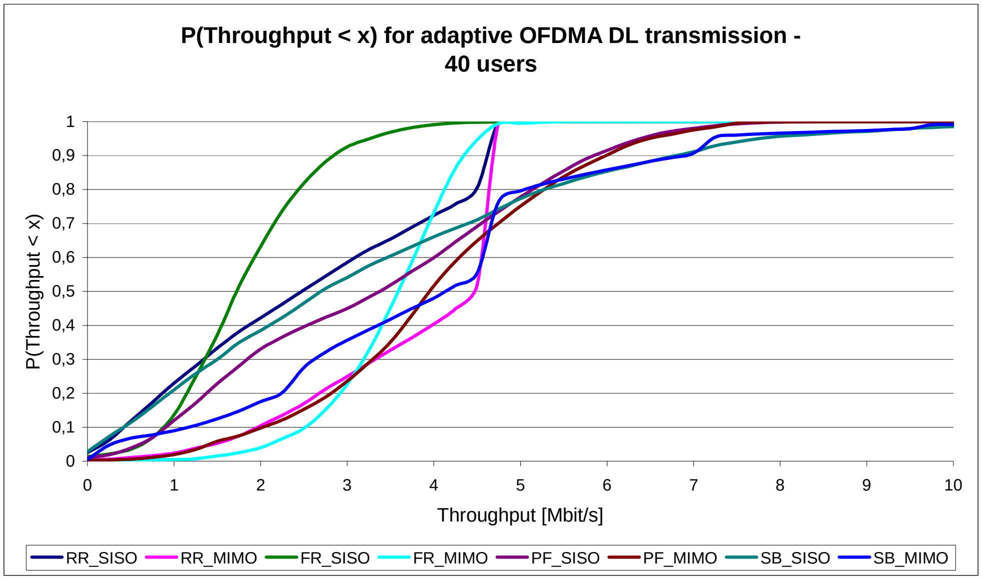

Figure 4-25: Probability to have a throughput lower than 'x' for adaptive OFDMA transmission in case of 40 users distributed within a cell – a comparison of MIMO and SISO schemes.

4.6 Handover Performance and Multi-mode capability with Relay-Enhanced Cells

This section presents a performance assessment of the multi-mode handover mechanisms for relay-enhanced cells that were presented in Section 3.5.

The simulation evaluations are conducted for two cases: inter-REC and intra-REC handover scenarios. The handovers between the different RAP types, namely BS↔BS, BS↔RN and RN↔RN, are analysed for each above-mentioned scenario using performance metrics mentioned in the Section 3.5. General simulation conditions are listed in Appendix 7.2.1. In order to efficiently simulate and evaluate the performance of the handover mechanisms, the mobility of the UT is set to move straight across the border between two RAPs forwards and backwards within a range of 20 meters.

Results for inter-mode handover, from TDD-mode to FDD-mode and vice versa, are described in subsections 4.6.1 and 4.6.2. The inter-mode handover from the FDD-mode to the TDD-mode occurs when a TDD-mode is detected and the inter-mode handover from the TDD-mode to the FDD-mode occurs when the BCH SINR of the TDD-mode is below a certain threshold and the FDD-mode has already been detected (see Section 3.5.4). The exact position of the inter-mode handover is dependent on the detection and disassociation thresholds described in Section 3.5.4.

4.6.1 Inter-mode Inter-REC handover

The investigated inter-mode inter-REC handover is the handover between two BSs. There are two BSs (BS1 and BS2) and one UT in this scenario. BS1 operates in TDD-mode and BS2 in FDD-mode. The UT supports both TDD- and FDD-mode. The distance between the two BSs is 310m. The scenario for the inter-mode inter-REC handover between the BSs is shown in Figure 4-26.

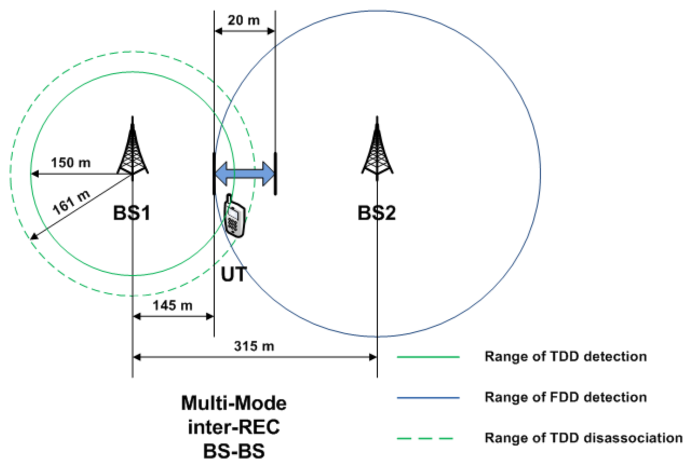

Figure 4-26: Inter-mode inter-REC handover between two BSs.

Figure 4-27 and Figure 4-28 show the DL and UL throughput, whereas in Figure 4-29 and Figure 4-30 the DL and UL packet delay are shown. Three handovers occur in this time interval. The UT is alternately connected via the two modes with the two BSs. The reason for the FDD-mode DL throughput being higher than the DL throughput above ARQ is that the UT moves away from the BS2 operating in FDD-mode and has still not reached the position where the TDD-mode is detected. Therefore the UL channel quality of the FDD-mode is getting worse so that the PER increases and causes ARQ retransmissions. Since the DL channel quality is still good, the UT receives many retransmitted packets through the FDD-mode at this moment, but the acknowledgements for the DL packets are not able to be transmitted successfully in the UL. The UL PER is shown in Figure 4-31.

The reason for the FDD delay being higher than the TDD delay is that there are two sub-frames in TDD, namely the DL and the UL sub-frame. The implemented scheduler can schedule packets directly in the next sub-frame, i.e. in the same frame, whereas in the FDD-mode packets can be scheduled at the earliest in the next frame.

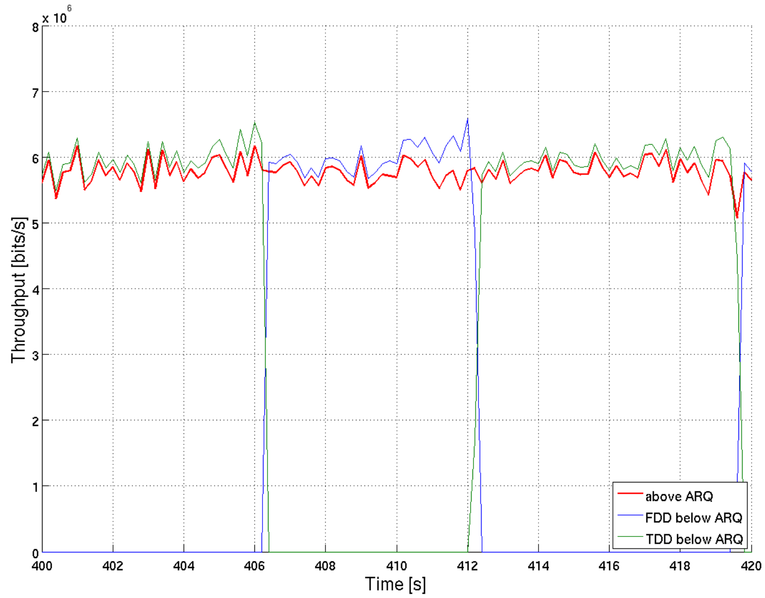

Figure 4-27: DL Throughput of inter-mode inter-REC handover between two BSs.

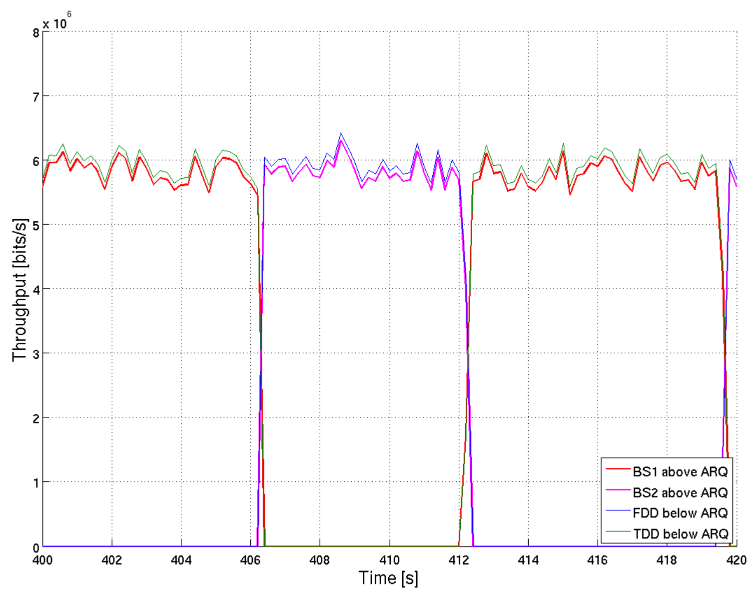

Figure 4-28: UL Throughput of inter-mode inter-REC handover between two BSs.

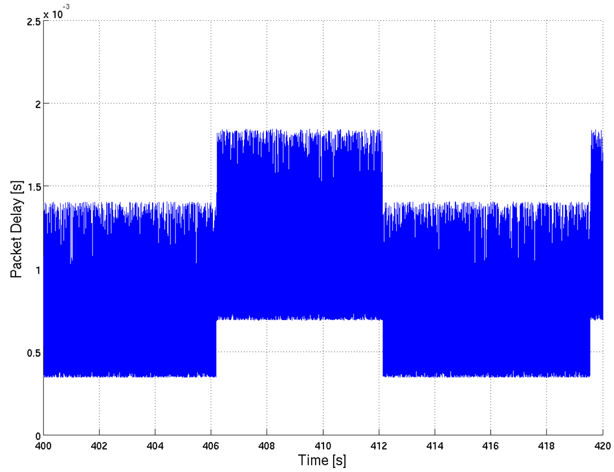

Figure 4-29: DL Packet Delay of inter-mode inter-REC handover between two BSs.

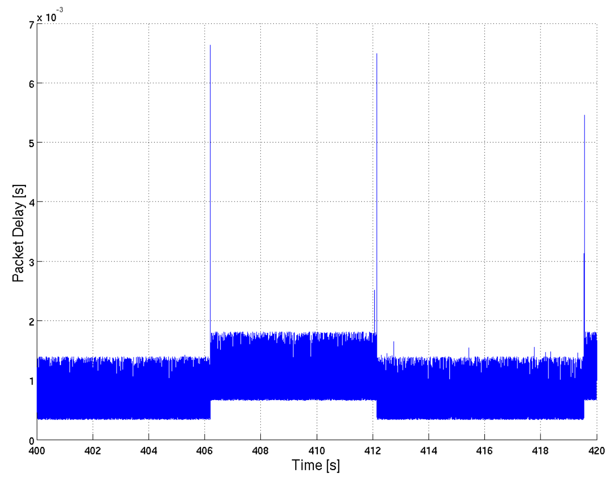

Figure 4-30: UL Packet Delay of inter-mode inter-REC handover between two BSs.

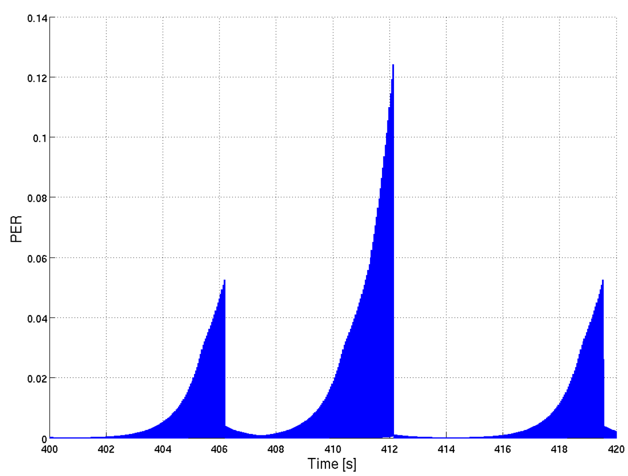

Figure 4-31: UL PER of inter-mode inter-REC handover between two BSs.

The average mean values and variances of packet delays and handover durations are listed in the Table 4-15 The minimum handover duration in this scenario is 0.0082s and the maximum is 0.0152s.

	Mean	Variance
DL packet delay	0.8833 ms	1×10^{-7}
UL packet delay	0.8702 ms	1×10^{-7}
Handover duration	11.5 ms	3.1055×10^{-6}

Table 4-15 Inter-mode inter-REC handover between two BSs: Delay and handover durations

4.6.2 Inter-mode Intra-REC handover

The first scenario for the inter-mode intra-REC handover is the handover between a BS and a RN. There is one BS with a RN and one UT in this scenario. The BS and the UT support both the TDD- and the FDD-mode. The RN only supports the TDD-mode. The BS and the RN are associated via the TDD-mode. The scenario for the inter-mode intra-REC handover between BS and RN is shown in Figure 4-32.

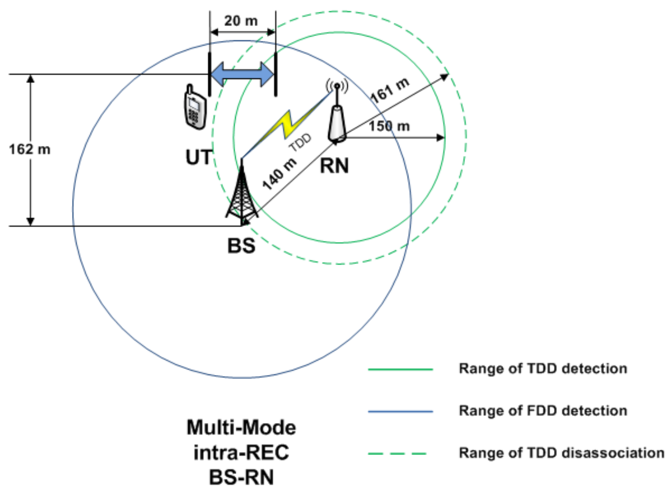

Figure 4-32: Inter-mode intra-REC handover between a BS and a RN.

The according DL and UL throughput curves as well as the delay values can be seen in Figure 4-33, Figure 4-34, Figure 4-35 and Figure 4-36. The results of this scenario are similar to the results of the inter-mode intra-REC handover scenario between the two modes of one BS. The UL packet delay of the FDD-mode is higher than the DL packet delay because the mobility area of the UT is chosen that way that it does not connect to the BS via TDD meaning that it is close to the cell edge. This leads to bad SINRs and accordingly to higher PER and higher packet delay. This is also the reason why the UL PER in the FDD-mode in this scenario is higher than the one in TDD. Whenever the UT is connected via TDD it is closer to its RAP. Whenever it is connected via FDD it is further away from its RAP. This can also be seen in the UL PER values shown in Figure 4-37. Furthermore, the delay is high after a handover in case it is an intra-REC handover. The reason again is the packets which were in the ARQ buffers before the handover and could be preserved. The exact values of the packet delays and handover durations are listed in Table 4-16.

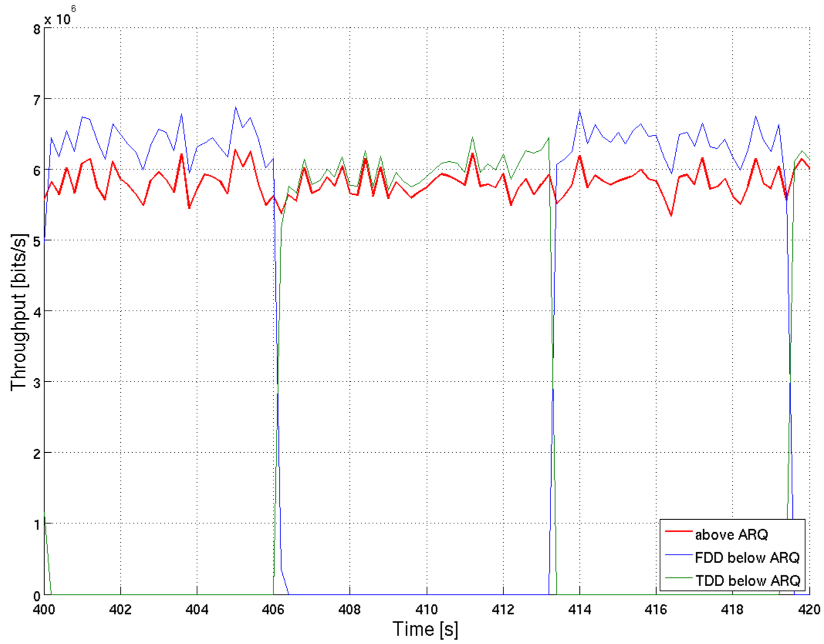

Figure 4-33: DL Throughput of inter-mode intra-REC handover between a BS and a RN.

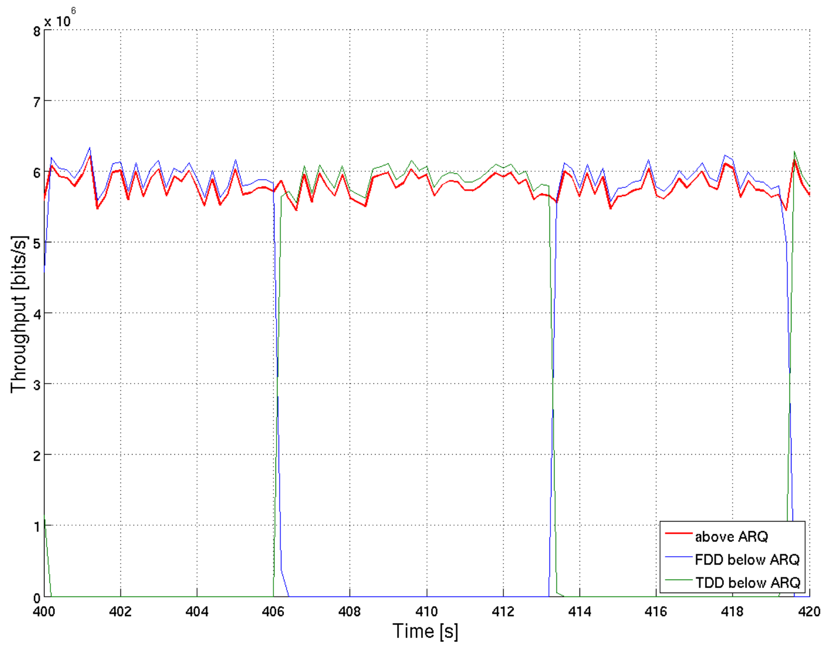

Figure 4-34: UL Throughput of inter-mode intra-REC handover between a BS and a RN.

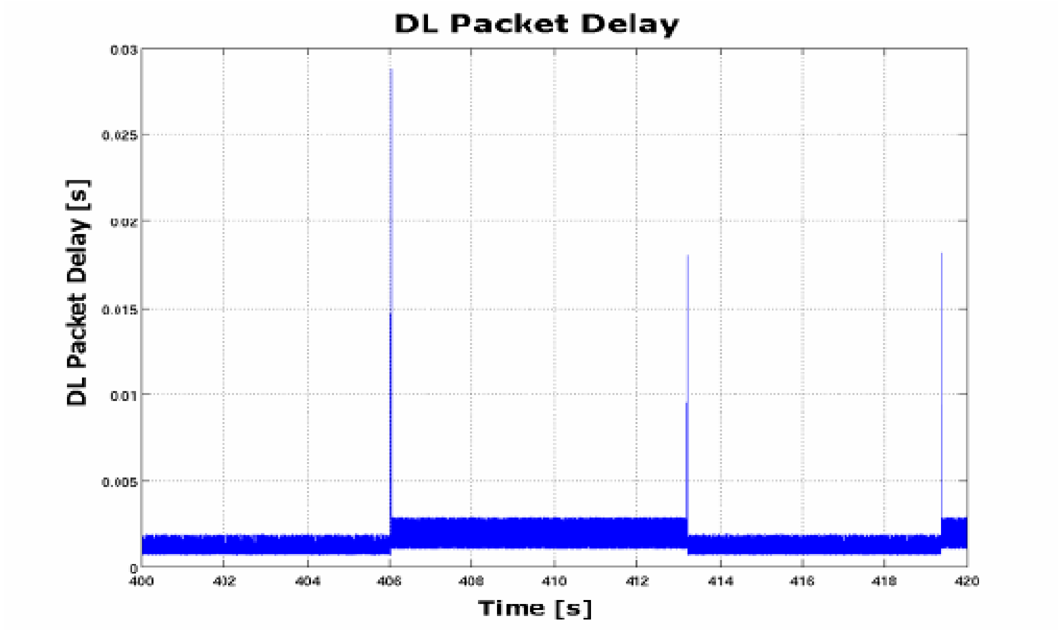

Figure 4-35: DL Packet Delay of inter-mode intra-REC handover between a BS and a RN.

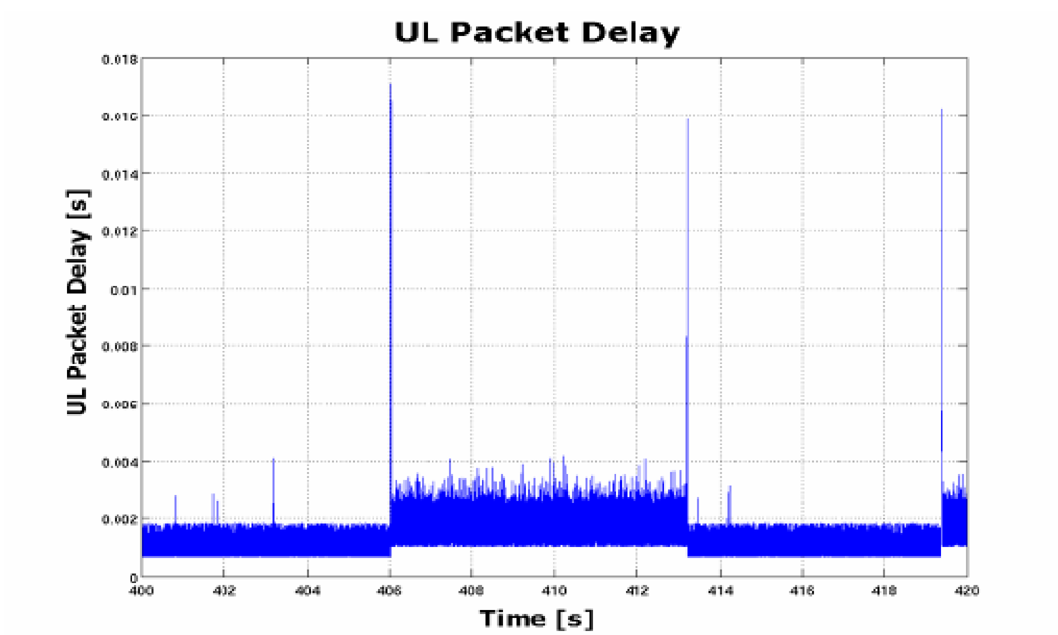

Figure 4-36: UL Packet Delay of inter-mode intra-REC handover between a BS and a RN.

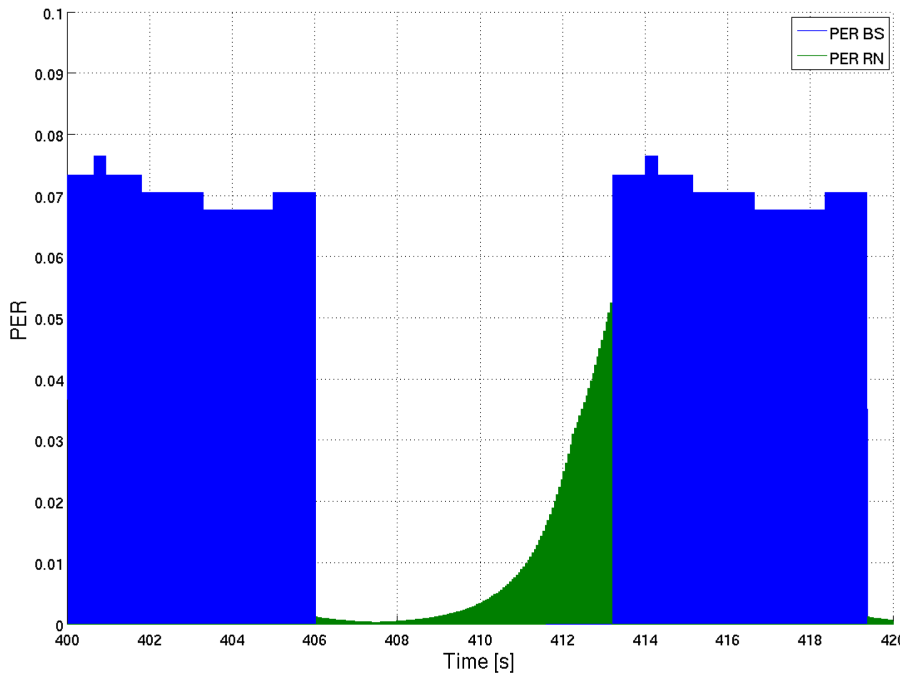

Figure 4-37: UL PER of inter-mode intra-REC handover between a BS and a RN.

	Mean	Variance
DL packet delay	1.5098 ms	4×10^{-7}
UL packet delay	1.5251 ms	5×10^{-7}
Handover duration	15.9 ms	8.0618×10^{-6}

Table 4-16 Inter-mode intra-REC handover between BS and RN: delay and handover durations

Figure 4-38 shows the Cumulative Distribution Functions (CDF) of the inter-mode (and for comparison purposes the TDD intra-mode) handover durations for the different scenarios. Because the FDD-mode as mentioned has slightly higher packet delay than the TDD-mode, and some of the handover signals, namely the request and acknowledgement of the disassociation, and also the association completed message, are sent in the frame, the inter-mode handover durations are slightly higher than the TDD intra-mode handover durations in the same scenarios. The number of hops has the highest impact on the handover duration. The handover duration is independent whether the handover is intra-REC or inter-REC, because the only difference between the inter-REC and the intra-REC is whether the packets in the mode-independent part, i.e. in the ARQ buffers are removed or preserved during the handover. Furthermore, it can be seen again that the handover duration for one scenario can differ in the range of a super-frame-length. This is because the signalling is partly sent over the BCH and RACH and these channels occur only once per super-frame. The mean value, variance, minimum and maximum of the handover durations of the different scenarios are listed in Table 4-17.

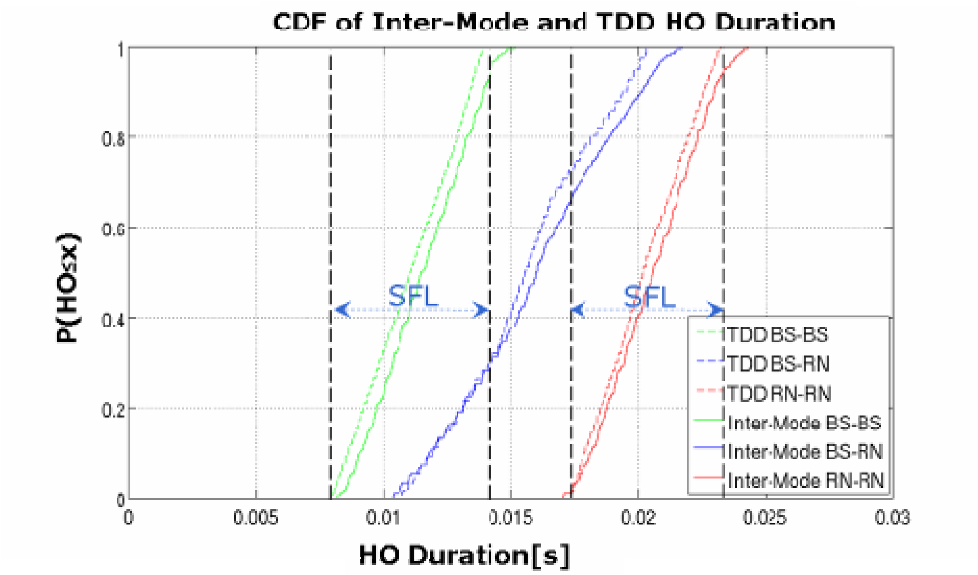

Figure 4-38: Durations of inter-mode handovers.

HO Type	Station Types	Mean	Min	Max	Variance
Intra-REC	BS-BS	0.0115 s	0.0082 s	0.0152 s	3.1055 × 10-6
Intra-REC	BS-RN	0.0159 s	0.0102 s	0.0212 s	8.0618 × 10-6
Intra-REC	RN-RN	0.0211 s	0.0171 s	0.0251 s	3.5470 × 10-6
Inter-REC	BS-BS	0.0115 s	0.0082 s	0.0152 s	3.1055 × 10-6
Inter-REC	BS-RN	0.0159 s	0.0102 s	0.0212 s	8.0618 × 10-6
Inter-REC	RN-RN	0.0211 s	0.0171 s	0.0251 s	3.5470 × 10-6

Table 4-17 Inter-mode handover results

4.6.3 Conclusions

By means of simulations the proof of the WINNER multi-mode MAC protocol concept has been shown. Therefore numerical performance assessment of delay, throughput and handover durations in inter-mode single- and multi-hop handover scenarios has been conducted above. The considered modes are the MA- and WA scenarios from [WIN2D6137]. The following conclusions can be drawn from these investigations:

- Parallel operation of different modes in a relay capable MAC protocol is feasible.
- It is possible to detect, select and switch the modes dynamically based on a given strategy.
- Handover mechanisms with mobility support work in various single-/multi-mode and single-/multi-hop scenarios.
- Keeping the user context in the End-to-End ARQ during an intra-REC handover is possible, in order not to delete these packets and so avoid a possible intervention of an upper-layer ARQ which would increase the delay.
- The handover duration is dominated by the number of hops and the used physical channels for signalling.

It has turned out that mobility support is a very sensitive issue. Even though it was assumed that the handover signalling is transmitted and received over error-free channels, the establishment and release of instances in the different station types has to be performed carefully at the right time, especially in the multi-hop case. Reasons for such problems could occur for example due to user data packets which were still in some buffers and were overtaken by the handover signalling packets, so that an instance in the receiving station was not available any more.

4.7 MAC Control Overhead Reduction by Fast Changing Semi-Static Resource Allocation

In [WIN2D461], the concept of Frame Descriptor Tables (FDTs) was introduced as a framework for controlling and reducing the total control signalling overhead.

The concept is especially efficient when physical transmission resources are to be allocated in a semi-static way. This is the case if packet flows have stable predictable properties and if the terminals are slowly moving. For example, a voice-over IP flow generates packets of known size with a regular interval. When a new such packet arrives, it can be mapped onto transmission resources (e.g. sets of chunks or B-EFDMA blocks) that are similar or the same as those used for transmitting the previous packet. Only *changes* of the block allocation then need to be signalled as out-band control information. If such changes are relatively infrequent, the control signalling overhead can be reduced. Frame descriptor tables can be used for this purpose.

To evaluate the performance of the FDT concept in WINNER Relay Enhanced cells (RECs) we in the following analytically calculate the overhead originated by the PHY and the MAC layer, normalised to the overall available resources in several REC scenarios. From this, the amount of resources available for transmission of user data can be derived. The resulting system capacity depends on modulation and coding schemes (MCS) applied to those resources. Moreover, the way these resources are allocated to the UTs has a strong impact on the system capacity. After stating the assumptions on applied MCS and the resource allocation scheme, example results are then presented for the resulting capacity, assuming non-frequency adaptive transmission.

The following assumptions are made for all results below.

- Overhead that is not included:
  - Cyclic Redundancy Check (CRC)
  - Flow identifier per transmission unit
  - FD identifier
  - Reservation of UL resources for resource requests
- Relation of DL and UL resources is not bound to 1:1
- The Resource Partitioning Information from BS to RN is assumed to be of the same size as Resource Allocation Info
- Only “Good Users” are considered => Allocation information is transmitted with BPSK½ (0.5 bits per symbol)
- The whole system bandwidth is used for non-frequency adaptive scheduling strategy
- SISO

In Table 4-18, all other parameters the calculations are based on are listed. Additional parameters are given in the text if needed. If available the parameters are specified according to [WIN2D6137].

Parameter	Value	Unit	Comment
Bandwidth	100	MHz	
Super-frame length	5.8896	ms	
Preamble duration	0.36	ms	
Frames per super-frame	8		
Frame length	0.6912	ms	
Number of chunks per frame in time and frequency direction	2 x 230		All used for non-frequency adaptive scheduling
Number of symbols per chunk	120		
Number of subcarriers	1840		
Chunk size	8 x 15		subcarriers x OFDM symbols
Block size	4 x 3		subcarriers x OFDM symbols
Number of blocks	4600		chunks x (chunksize/blocksize)
Number of pilots per block	1		
UL Sync	2	symbols	
RAC	6	symbols	
Guard time	1	symbols	
DL Sync	3	symbols	

BCH length	4	symbols	
Resource allocation table			Resource allocation info is send in a hierarchical manner a modulation and coding reference table (MCR) describing the way the second table has to be decoded. The second table (FCH) contains the relevant resource allocation info.
Size of MCR entry	5	bits	
Number of entries per MCR	5		
Coding of MCR	2	symbols/bit	BPSK1/2
Size of FCH entry	43	bits	flow address (9 bits), segment size (9 bits), starting position of segment (9 bits), mcs (5 bits), spatial scheme (5 bits), HARQ process number (6 bits) (These figures are preliminary. The final ones will be contained in [WIN2D61314])
Coding of FCH entry	2	symbols/bit	
Number of flows per UT	2		One UL + one DL
Number of UTs	varying		

Table 4-18: Parameters for calculation.

4.7.1 Evaluation scenario

To investigate the performance of the FDT concept in RECs, we use the four scenarios depicted in Figure 4-39. In each scenario, up to 500 UTs are served, each with one up- and one downlink by one BS optionally supported by a) 1 up to d) 4 RNs. When adding a UT it is associated to the BS/RN that has the least number of UTs already associated, prioritising the BS.

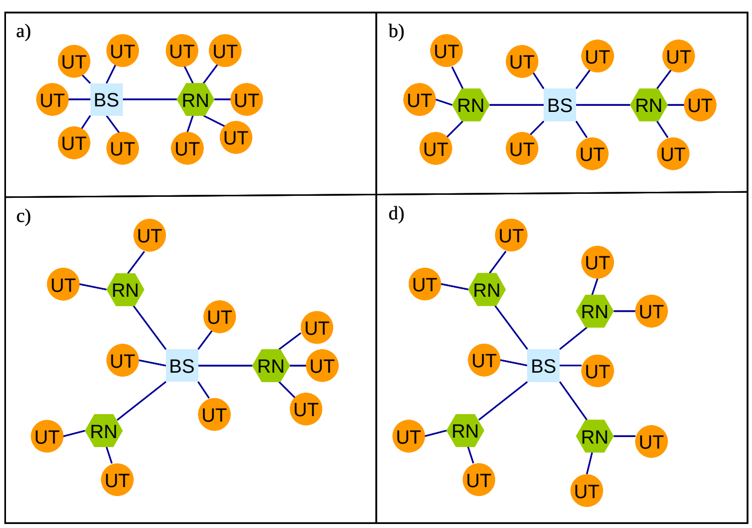

Figure 4-39: Evaluation Scenarios with exemplary 10 UT associated to 1 BS and a) 1RN, b) 2RN, c) 3 RN, d) 4 RN.

4.7.2 Variable periodicity of Frame Descriptor updates

In the first investigation performed within the scope of this work,

- One frame descriptor is assumed to be kept within the FDT for a fixed period of several frames.

- After this period elapses, a new frame descriptor is calculated and sent out by the BS to the UTs.
- These substitute the old entry in their FDT for this newly received frame descriptor.

The efficiency of the concept scales up with the number of stored frame descriptors in the FDT. To get an impression of the potential of the concept and to ease the understanding of the results, we have chosen this basic approach of implementing it. Applying the FDT concept in particular this way is a trade-off between flexibility and overhead. If the layout of the frame is kept unchanged for too long, the needs of a connection scheduled within the frame descriptor may have changed and resources may be allocated unnecessarily. If the frame descriptor is changed too often, the efficiency is reduced. In order to find out which periodicity for changing the frame descriptor is reasonably, investigations have been carried out with the results presented in Figure 4-40. This figure shows the overhead vs. the total number of UTs that are scheduled per frame, for different periodicities of the frame descriptor updates. The scenario used is that of 2 RNs (compare to Figure 4-39). The FDT concept is used for controlling all RAP controlled resources, BS controlled as well as RN controlled ones.

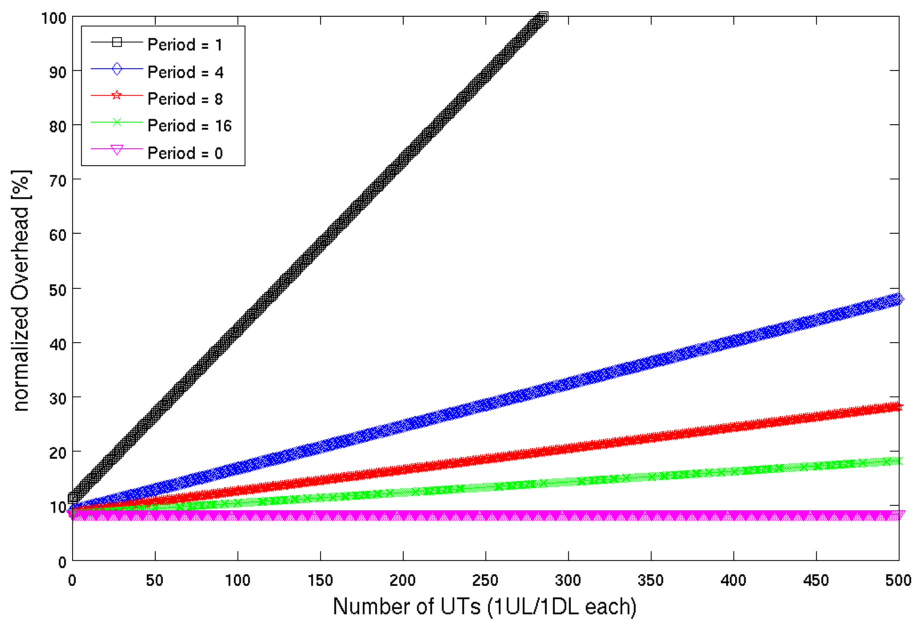

Figure 4-40: Overhead with FDTs vs. total number of UTs scheduled per frame depending on the period of the FD update. Scenario with two relay nodes.

When changing the frame descriptor in every frame (Period = 1) the overhead increases the most, up to nearly 90 % when scheduling 250 UTs per frame. The run of the resulting overhead curve is identical to the result when not applying the FDT concept at all as there is no additional overhead introduced by the FDTs themselves.

The longer the time between an update of a frame descriptor, the less signalling is needed. Thus, the overhead can be reduced by increasing the period of frame descriptor changes. But another fact becomes apparent when examining Figure 4-40. The rate of gain in overhead is getting smaller with increasing periodicity of frame descriptor changes. This becomes intuitively clear when imagining the same amount of signalling being spread out over an increasing interval. The gain is growing logarithmically. Thus the highest investigated periodicity (Period = 0, equals no signalling at all) with about 8% overhead (independent of the number of scheduled UTs) can only reduce the overhead arising at a periodicity of 16 by about 5% when scheduling 250 UTs.

On the basis of these results, the periodicity for changing the frame descriptor is set to **16 frames** for the upcoming investigations. This seems to be a reasonable trade-off between flexibility in resource allocation and efficiency regarding the overhead. It is important to understand that the results presented below, based on a period of 16, do not show the upper limit of gains that can be obtained by applying the FDT concept. Assuming one knows the characteristic of a flow in the sense of QoS requirements, e.g. minimum throughput, maximum delay which will be the case for the traffic of some services which are very relevant for the WINNER air interface, e.g. Voice (VoIP), Video (IPTV, Video on Demand), it is possible to obtain higher gains without any loss of flexibility.

4.7.3 Overhead reduction due to FDTs

The following investigations are serving the evaluation of the performance of the FDT concept in REC scenarios. Therefore the overhead originated when a BS, supported by 0, 2, 4 RNs, serves up to 500 UTs is computed. The resulting overhead vs. the number of UTs scheduled per frame, applying Round Robin scheduling with/without FDTs is shown in Figure 4-41. Moreover the overhead without FDTs, resulting, when no respectively one UT is scheduled per frame, is given to ease readability.

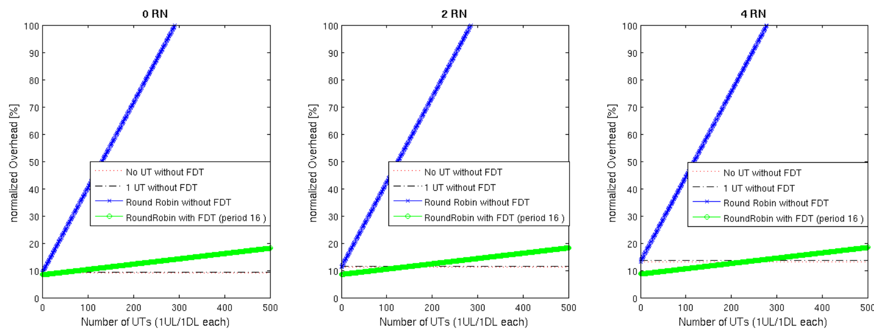

Figure 4-41: Overhead with/without FDTs vs. total number of UTs scheduled per frame with a) 0RN, b) 2RN, c) 4RN.

The curves “No/1 UT without FDT” show the overhead introduced even if No/1 UT is granted resources in a frame, thus e.g. corresponding to the overhead introduced by preamble and MCR in the case of No UT.

The results for the case without FDTs, given in Figure 4-41a) show an overhead of about 9% for no UT respectively 1 UT and up to 87% for 250 UTs. It is visible that applying FDTs in the case of 250 UTs the overhead can be reduced by about 74% to about 13%. Moreover, also in the case of no UT scheduled per frame, the overhead is reduced as the resources to be allocated by the BS to serve the RN are incurred independent of the number of scheduled UTs and are allocated more efficiently with the help of FDTs.

The increase of this generic overhead when increasing the number of RNs in the scenario is visible from Figure b) and c) giving the results for 2 respectively 4 RNs. Comparing the results for 250 UTs it is visible that the application of FDTs allows for a reduction of overhead of about 76% for 2 RN and for about 78% for 4 RNs. These results show with respect to the control signalling the potentials of relaying in particular when considering the implementation of RNs in the system concept right from the start. The slight increase of overhead is introduced by the transmission of MCR tables by each RN, but can be alleviated by the FDTs as can be seen from Figure 4-42, where it is visible that the overhead applying the FDT concept (period = 4,8,16,0) increases more smoothly as in the case without FDTs (period = 1). Comparing the results given in Figure 4-40, Figure 4-41 and Figure 4-42 with results for the same scenarios omitting the overhead introduced by the PHY, e.g. pilots, it turns out that the possible reductions of overhead are identical and thus that the reduction of overhead achieved with FDTs is only based on a more efficient MAC protocol.

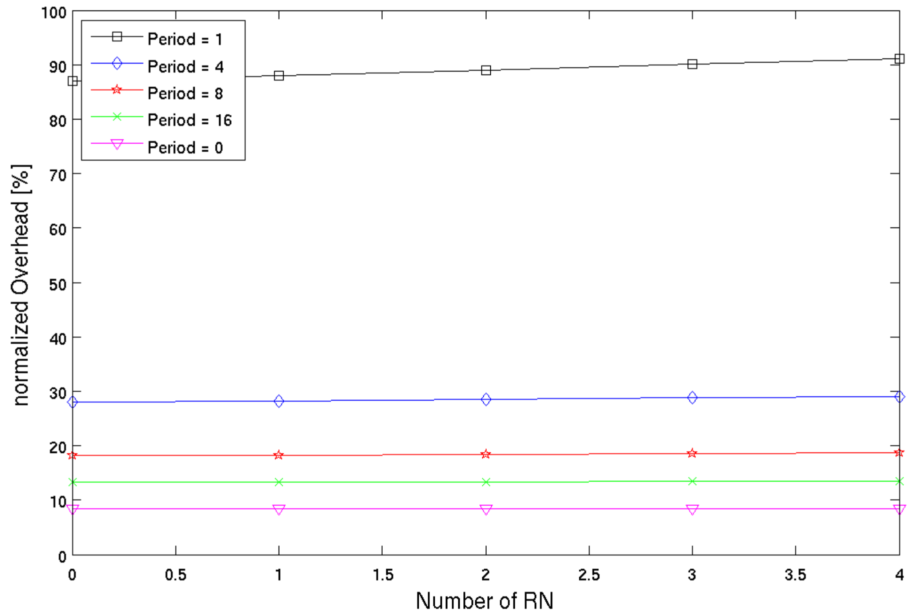

Figure 4-42: Overhead with FDT vs. number of RNs depending on the period of FD updates (250 UTs).

4.7.4 Capacity gain due to FDTs

From the results shown, the amount of resources available for transmission of user data can be derived. The resulting system capacity depends on Modulation and Coding Schemes applied to those resources and moreover the way these resources are allocated to the UTs has a strong impact on the system capacity. In the following the resources are allocated to the UTs in a way that the flow of each UT respectively Remote User Terminal (RUT), which describes a UT served by a RN, has the same data rate. The resulting system capacity *C* [Mbit/s] depends on the number of bits available for user data *B_u* and the duration of the maximum number of available symbols *D_max*:

$$C = \frac{B\_u}{D\_\max * 1\exp 6}$$

with *B_u* depending on the symbols allocated to UTs *S_ut*, the number of flows between BS and UTs *N_f_ut*, the number of bits per symbol used for the user data between BS and UT *BpS_u_ut*, the symbols allocated to RUTs *S_rut*, the number of flows between RN and RUTs *N_f_rut* and the number of bits per symbol used for user data between RN and RUTs *BpS_u_rut*:

$$B\_u = S\_ut * N\_f\_ut * BpS\_u\_ut + S\_rut * N\_f\_rut * BpS\_u\_rut$$

with *S_ut* and *S_rut* depending on *N_f_ut*, *N_f_rut*, the number of symbols available for user date *S_u* and the relative data rates *T* and *C*:

$$S\_ut = \frac{1}{(N\_f\_ut + N\_f\_rut) * (\frac{T}{2} + \frac{C}{2})} * S\_u$$

$$S\_rut = \frac{\frac{T}{2}}{(N\_f\_ut + N\_f\_rut) * (\frac{T}{2} + \frac{C}{2})} * S\_u$$

with S_u depending on the maximum number of available symbols S_max and the number of symbols needed for signalling S_sig :

$$S\_u = S\_\max - S\_sig$$

and the relative data rates T and C:

$$T = \frac{BpS\_u\_ut}{BpS\_u\_rut}$$
$$C = \frac{BpS\_u\_ut}{BpS\_u\_rn}$$

The MCS where applied in the following way:

$$BpS\_sig = BpS\_u\_ut = 0.5$$
$$BpS\_u\_rut = BpS\_u\_rn = 3$$

while 0.5 corresponds to BPSK½ and 3 to 16QAM ¾. The higher MCS for multi-hop flows on the second hop supports the idea of associating UTs to RNs in the case of a better channel between UT and RN than between BS and UT. Moreover it seems reasonable to assume the channel between BS and RNs to allow for 64QAM ¾ MCS. The resulting capacity is shown in Figure 4-43 with one BS serving up to 500 UTs supported by 0, 2 or 4 RNs. It is important to say that in the following more than one FD is assumed to be stored in the FDTs. The update period = 16 allows for the update of one of these FD entries every 16 frames whereas every 16 frames another FD can be updated.

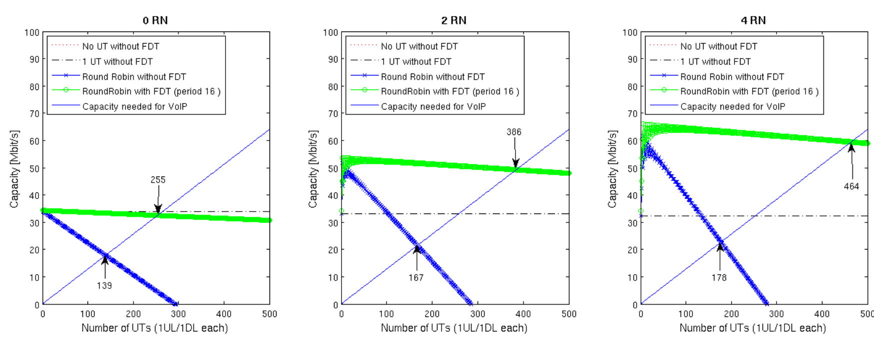

Figure 4-43: Capacity of REC with/without FDTs vs. total number of UTs scheduled per frame with a) 0RN, b) 2RN, c) 4RN.

It is evident that with FDT the capacity is improved for all three scenarios. To illustrate the improvement, each result contains a curve representing the capacity necessary to serve the indicated number of users (equal the “Number of UTs”) with a VoIP call (128 kbit/s per UT). From this it is possible to identify how many users can be served. In the scenario a) without any RN supporting the BS in serving the UTs without FDT 139 user can have a VoIP call in parallel whereas with FDT even 255 users can be served with a VoIP call. This is equivalent to 83% more users. This improvement increases for scenario b) with 2RN to 131% and for 4RN up to 161%.

Investigations (results are not in the figures) with the following modified assumptions:

- VoIP call requires 16 kbit/s,
- 64QAM ¾ on all links
- update period is 24 (corresponding to 3 Superframes)

show that with the help of FDTs for the scenario without any RN 5174 users and with 4 RNs still 4380 users can have a VoIP call. It is important to know that this results still do not represent the upper bound as not all possibilities are taken into account, e.g. partial update of the frame descriptors or considering higher link bit rates realized by MIMO techniques.

Examining Figure 4-44, the gain in capacity can well be seen. Depending on the period for the frame descriptor update applying FDTs, the capacity for 4 RNs is between 8 times (for period 4) up to 10.3 times (for period 0) higher than without FDTs. In the case of FDT update period 16 and 4 RNs the capacity is 9.7 times higher as without FDTs.

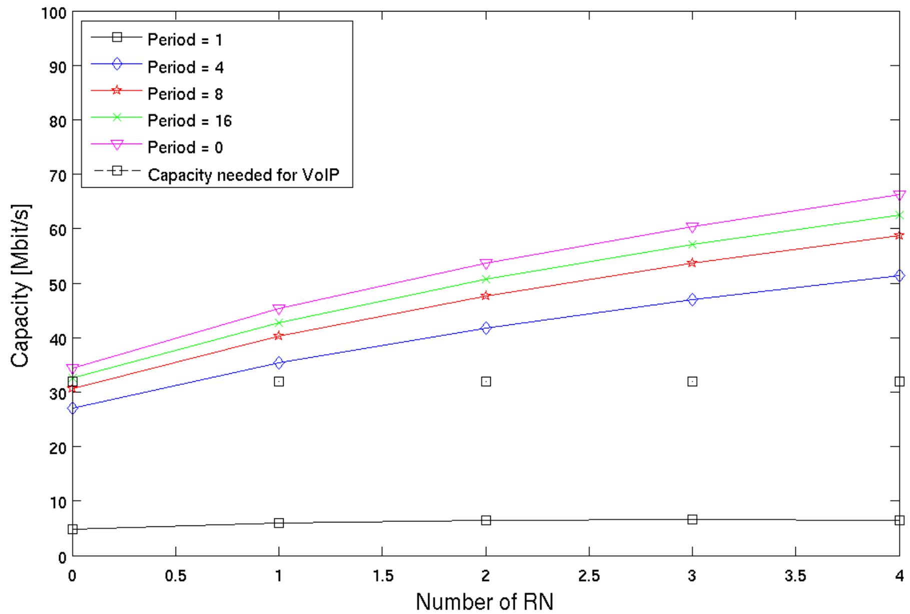

Figure 4-44: Capacity with FDT vs. number of RNs depending on the period of FD updates (250UTs).

4.7.5 Conclusion

The focus of this work was on the performance evaluation of the Frame Descriptor Table concept, amongst others, invented for minimizing the overhead introduced by MAC protocols using a frame based resource reservation strategy, in WINNER REC scenarios. As REC is important technology component for metropolitan area deployments, these results have been included in this deliverable.

It turns out that applying FDTs in the context of resource allocation information in the case of 250 UTs, the overhead can be reduced by about 74% in a REC without any RN, by about 76% with 2 RN and by about 78% with 4 RNs. All results assuming an update period of 16 frames, i.e. every 16th frame the resource allocation information is updated according to the current status of the queues. Thus, the results are based on a scheme of the FDT concept which is very easy to implement and which offers great potential for further improvement.

Assuming particular MCSs on the different links and a RRM scheme allocating resources to all links in a way that all UTs can be served with the same user data rate, it turns out that with FDTs, the resulting system capacity is improved for all three scenarios. Normalizing the results to VoIP calls (128 kbit/s) the gain can be measured: in the scenario without RN, the FDT concept allows for serving about 83% additional users compared to the case without FDTs. For the scenario with 2 RN, this gain increases to 131% and with 4RN it reaches about 161%.

To summarise, the FDT concept performs very well in the WINNER REC in terms of reduced overhead and improved system capacity.

4.8 Spectral Resource Management Performance Evaluation

In this section, we address the performance evaluation of spectral resource management where we mainly focus on the short-term spectrum assignment. The task at hand is to efficiently exchange spectrum resources between different RANs of the same technology on a fast basis while managing the interference inflicted to neighbouring cells. The results obtained are at RAN and cell level.

4.8.1 Scenario description

Short term spectrum assignment between two different WINNER RANs (RAN1 and RAN2) at the cell level is investigated here Figure 4-45. The focus is on the downlink of the multi-cellular OFDMA system as applied in WINNER RANs. WINNER Metropolitan Area (MA) is considered with TDD as the preferred mode, the results are obtained at network level. It is assumed that two separate distinct spectrum bands are assigned for two RANs during long term assignment (LT). The spectrum assignment in LT is based on longer timescales and deals with average or expected spectrum resources. Within LT assignment average spectrum resources are taken into account from traffic demand curves to assign spectrum resources cell level. But the actual spectrum resources or the spectrum resources demand varies from the average value depending on the dynamicity of spectrum usage in each RAN. Therefore, to efficiently assign these spectrum resources during ST assignment period, spectrum resources are assigned based on the actual spectrum resources rather than the average values. The difference between the actual usage of spectrum resources against the average assignment of spectrum resources results in an additional or insufficient usage of resources at each cell. This results in spectrum boundaries changes in both RANs (RAN1 and RAN2).

4.8.2 Inter RAN Interference Issues in ST Assignment

In this scenario during ST assignment cell C_1 of RAN_1 has extra spectrum resources to negotiate with cell C_{11} of RAN_2. In this case C_1 is considered as the generous cell and C_{11} is considered as the greedy cell. For an efficient spectrum assignment during each ST assignment period, the impact of interference between new spectrum usages of cell C_{11} in RAN_2 on the cell cluster of cell C_1 in RAN_1 needs to be measured. Figure 4-45 illustrates the impact of inter-cell interference on cell clusters in ST assignment once cells C_1 and C_{11} are in the negotiation of spectrum resources. This negotiation will automatically impact the neighbouring cells of C_1 (C_2, C_3, C_4, C_5, C_6 and C_7). In this scenario it is assumed the interference is only imposed towards the cells in the first tier.

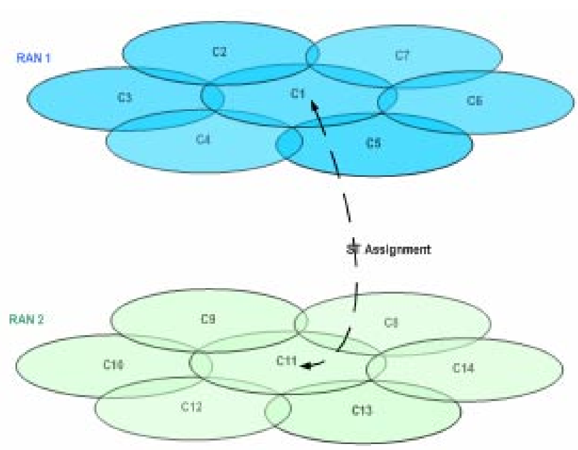

Figure 4-45: Illustration of ST spectrum assignment between cells from RAN_1 and RAN_2.

It is important to know the resource allocation patterns of each cell when investigating the interference between two negotiating cells. Since the objective of this work is to investigate the change of spectrum boundaries during ST assignment resource allocation in each cell is assumed as in Costas arrays. ST assignment period is considered as the TDD super-frame duration of around 6ms. Within WINNER TDD mode of operation the super frame size is 230 chunks in frequency and 16 chunks in time. Therefore each super-frame contains 230*16 = 3680 chunks. Therefore in this work the time-frequency (T-F) mapping (or chunk mapping) is based on a truncated Costas sequence of length 230. Costas arrays are $n*n$ arrays consisting of dots and blanks with exactly one dot in each row and column [GT84]. According to Costas array representation Figure 4-46 illustrates the chunk resource allocation pattern for cell C_i (where i =2, 3, 4, 5, 6) and chunk resource allocation pattern of C_{11} respectively both time and frequency. The initial chunk allocation pattern is a random allocation of any cell C_i (where i =2, 3, 4, 5, 6). This allocation pattern is called the basic allocation pattern. For example initial random allocation pattern in Figure 4-46 can be assigned to $Cell_2$ of RAN_1. Once this is obtained then for any other cell in the 1st tier and super-frame duration the chunk allocation pattern can be acquired as a cyclic frequency shift of the basic allocation pattern (for Cells i =3, 4, 5, 6).

After ST assignment cell negotiation between C_1 and C_{11} some chunks given to the greedy cell (C_{11}) can interfere the allocation of the same chunk in the neighbouring cells (neighbouring cells in the 1st tier of C_1 of RAN_1). Therefore in ST assignment to minimise the interference in the neighbouring cells of the generous cells caused by the deployment of negotiated chunks in greedy cells it is important to define a maximum allowable interference threshold ($P_{threshold}$).

A binomial distribution describes the probability P_i of a simultaneous allocated chunk as:

$$P_i(x) = C_x^n k^x (1-k)^{n-x} \qquad (1)$$

Where n is the number of cells, x the number of simultaneous chunk allocations of the desired chunk by the interfering cells and k is the number of allocated chunks. For a successful spectrum assignment at cell level the following equation (2) has to be fulfilled where A is the number of negotiated chunks between RANs:

$$\sum_{i}^{A} P_i < P_{threshold} \qquad (2)$$

Where $P_{threshold}$ is the maximum allowable interference within ST negotiation that can be agreed between the cells of 1st tier in RAN_1.

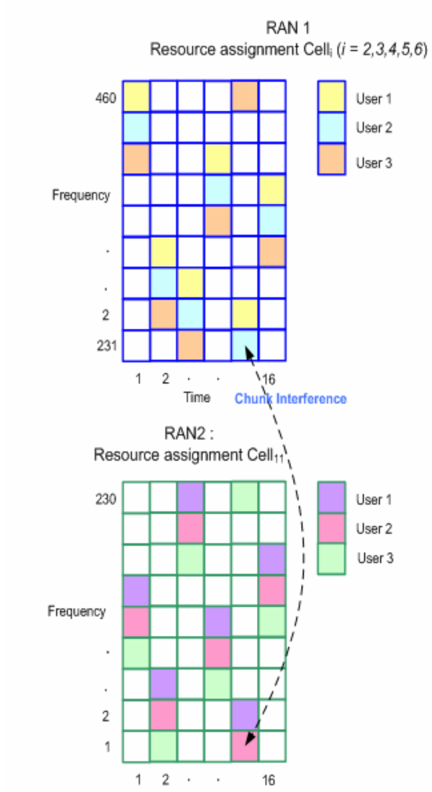

Figure 4-46: Inter-cell interference avoidance using COSTAS Array.

4.8.3 Simulation Results and Discussion

The following section present the simulation study describing the issue of inter cell interference in ST assignment in the above scenario. In this case WINNER MA deployment with TDD mode of operation is considered. The ST assignment period is considered as super-frame duration of 230 chunks in frequency direction and 16 chunks in time direction. Therefore truncated Costas array representation of 230*16 is considered for resource allocation patterns in each cell. At the same time in order to avoid intra-cell interference in a single cell only one user is assigned to a frequency chunk at one time. Also it is assumed in the neighbouring cells, the same chunk is allocated to different users who are separated in distance.

For each cell the average number of chunk usage is considered as a constant value. In the first case only 50 average frequency chunks (from the available 230 frequency chunks) or around 20% of the available frequency chunks are used in the generous cell (C_1) in each chunk duration (time slot). In the second case 80 average frequency chunks (around 35%) are used in cell C_1. In both cases the generous cell (C_1) opens chunk negotiation with the greedy cell (C_{11}) of RAN_2. Both cases are investigated against different interference threshold ($P_{threshold}$) that is the maximum allowable interference within ST negotiation. Also the generous cell can consider the rather selfish approach of not agreeing with neighbouring cells about interference levels the negotiated chunks can impose on the 1st tier of cells. At the same time it is investigated with the increase of agreement between neighbouring cells the amount of negotiated chunks decrease due to interference to neighbouring cells. This is being investigated starting from the selfish approach (where no neighbouring cells are considered for interference agreement) and step by step increase of the number of neighbouring cells considered in interference agreement.

For example Figure 4-47 presents the available percentage of chunks for negotiation for different interference threshold values and with different number of neighbouring cells in agreement. This is the case for average chunk usage is 20% of the available chunks. As can be seen in the case of selfish approach 100% of the unused chunks are available for negotiation between C_1 and C_{11} irrespective of the interference causing to the first tier. When neighbouring cells are taken into account, within a given maximum interference value the amount of chunks available for negotiation decreases.

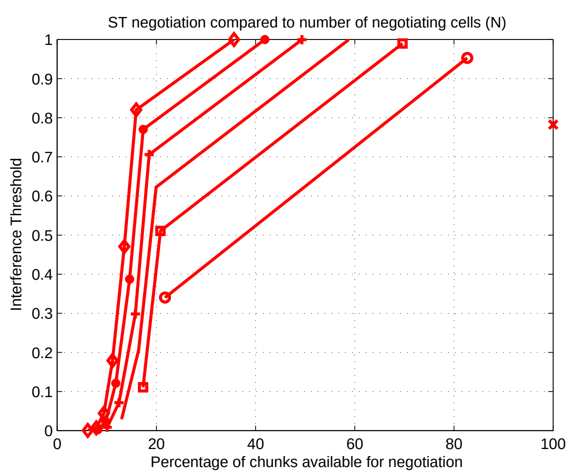

Figure 4-47 Probability of interference threshold Vs Percentage of chunks for negotiation (average chunk usage 20%).

For example it can be seen from Figure 4-47 for the maximum interference threshold value of 0.82, when 2 cells have agreed on interference only 67% of available chunks are given for negotiation. When number of cells in agreement for interference increases to 3, 4, 5, 6 and 7 the percentage of available chunks for negotiation between C_1 and C_{11} decreases from 67% to 50%, 38%, 28%, 21% and 15% respectively. Therefore in the case of selfish approach where only C_1 makes the decision for negotiation irrespective of the interference it causes to 1st tier, 100% of the unused chunks are available for negotiation. At the same time when C_1 involves all the cells in the 1st tier for decision making this result in only 15% of the unused chunks available for negotiation. The similar behaviour is investigated for the case where the chunk usage is 35% of the available chunks Figure 4-48.

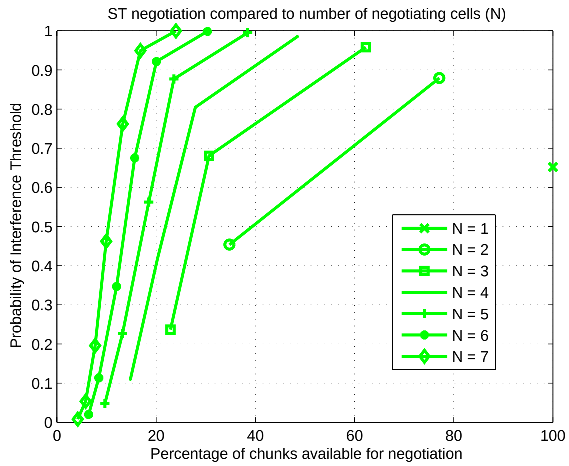

Figure 4-48: Probability of interference threshold Vs Percentage of chunks for negotiation (average chunk usage 35%).

For the maximum probability of interference threshold value of 1 in the case of average chunk usage of 20% when C_1 involves all the cells in the 1st tier for decision making this result in only 35% of the unused chunks available for negotiation. For the same maximum probability of interference threshold value of 1 in the case of average chunk usage is 35% when C_1 involves all the cells in the 1st tier for decision making only 25% of the unused chunks are available for negotiation.

4.8.3.1 Performance Evaluation in ST Assignment

This section investigates the performance of ST assignment in inter-RAN scenario.

RAN Topology and Traffic Demand

The cell topology of RAN_1 and RAN_2 is as follows Figure 4-49. The topology considered in this study consists of each RAN having 16 cells where only two cells are trying to negotiate spectrum resources on a fast basis. Cells in RAN_1 are numbered from Cell id_1 to Cell id_{16} whereas cells in RAN_2 are numbered from Cell id_{17} to Cell id_{32}.

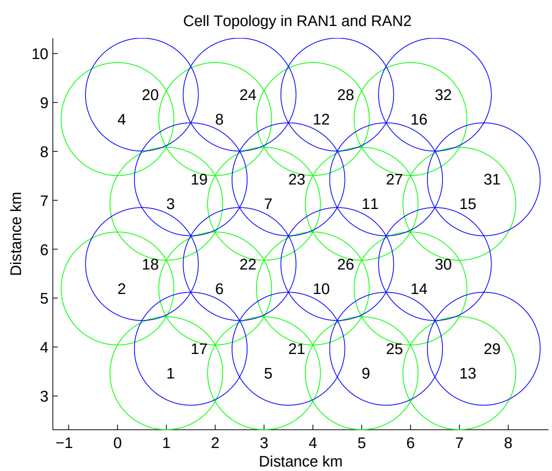

Figure 4-49: Cell Topology of two networks RAN1 and RAN_2

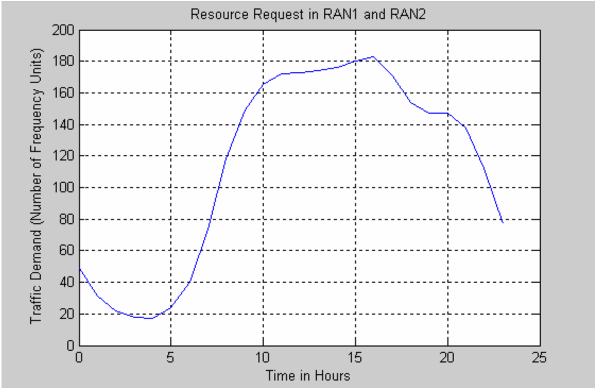

Figure 4-50: Pattern of traffic in a cell of RAN_1 and RAN_2 with the same average.

Figure 4-50 above illustrates the traffic demand pattern for each cell. The trend of the demand curves are based on average values of real traffic patterns provided by one major European operator. The *y* axis presents the average number of spectrum resources and the *x* axis is during hours of the day (24 hour period). The average number of spectrum resources per day is calculated by considering the mean demand over a weekly period. 50% of the data usage and 50% of voice usage is considered in resource request. Due to operational limitations it is assumed during the maximum demand only 80% of the spectrum resources are utilized. That is for example during the busy hour period from the available 230 frequency chunks only (08*230) = 184 frequency chunks are used.

Although the average number of requested chunks can be drawn from the Figure 4-50 during each ST assignment there is an instantaneous variation in actual requested number of chunks. During each ST assignment period the actual number of requested chunks is expressed as a random number drawn from a normal distribution (μ , σ), where μ is the average value from the traffic demand curves for each RAN and σ is the standard deviation where $\sigma = 0.1 * \mu$.

Cell Pair Identification for ST Assignment

The Figure 4-51 presents the instantaneous resource request variations within the considered RAN topology. The *x* axis corresponds to the corresponding cell pairs selected from each RAN which may be the negotiation pairs in ST assignment. Depending on the considered RAN topology 16 cell pairs are selected. The spectrum assignment given by LT is at longer time scales than in the ST spectrum assignment. ST assignments take care of the tiny fluctuations of the traffic demand and negotiate resources accordingly. The following illustrates additional or insufficient frequency chunks in each cell pair due to traffic demand fluctuation at time 21 hours where the average number of frequency chunks is are 147 from the traffic demand curves. For example cell pair with Cell ID_1 (RAN_1) and Cell ID_{17} (RAN_2) may not involve any negotiation as they both need extra resources. On the other hand Cell ID_3 and Cell ID_{19} may choose to negotiate spectrum resources with each other since Cell ID_{19} has extra resources and Cell ID_3 needs more resources.

For each RAN we define *greedy cells* and *generous cells* depending on the additional or insufficient resources. When ($N_a > N_d$) then these cells are categorise as generous cells where extra resources are available for negotiation. If ($N_a < N_d$) these cells are greedy cells since they are starving for more resources. N_a is the number of resources allocated to each cell during LT assignment and where as N_d is the actual number of resources needed from the traffic demand curves. For example the Cell ID_1 and Cell ID_{17} are considered as greedy cells where as Cell ID_{19} can be considered as a generous cell. During ST assignment period only generous and greedy cells negotiate with each other.

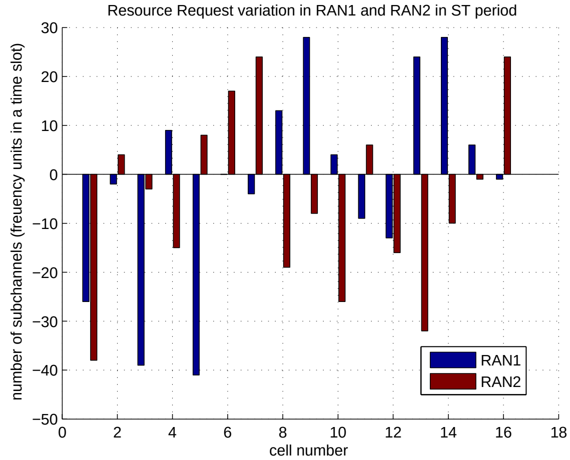

Figure 4-51: Resource Request variation in RAN_1 and RAN_2 in ST period (positive means available, negative means demand).

Cell Pair Selection Algorithms for ST Assignment

To avoid conflicts between cell pairs only a single cell pair is selected within each ST assignment period. The selection of cell pair is based on the following two algorithms. The first algorithm is based on the selection of cell pair with least satisfaction. In this case the generous cell satisfies the minimum requirement of the greedy cell. The second algorithm is based on cell pair with the most flexibility in allocating chunks. In this case generous cell provides the maximum satisfaction to the greedy cells or much more than the required resources from the greedy cell. Having more resources than the required allows flexibility in resource allocation for the greedy cell thus avoiding interference to neighbouring cells of the generous cell.

4.8.3.2 Discussion of Results

Figure 4-52 presents the comparison between the above mentioned algorithms once applied to the ST assignment between two RANs. Selection of cell pair is based on in the first cast is according to the least satisfaction criteria. In this case the amount of offered frequency chunks in the generous cell is similar to the number of extra frequency chunks required by the greedy cell. In the second case the cell pair selection is based on maximum flexibility criteria. In this case the generous cell offers much more than required by the greedy cell. For successful ST assignment performance it is necessary to reduce extra interference caused by offered frequency chunks to the neighbouring cells of the generous cell. With plentiful resources greedy cell has the flexibility of deploying chunks minimising interference to neighbouring cells in the 1^{st} tier of the generous cell.

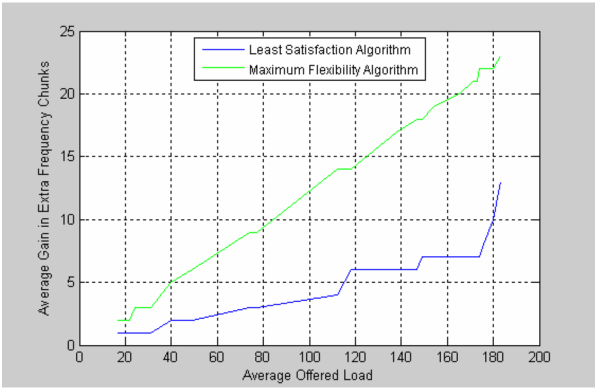

Figure 4-52: Algorithm Comparison for Average Gain in ST assignment.

In Figure 4-52 the *x* axis represents the average offered load in each RAN. This is given in terms of frequency units. The *y* axis represents the average extra frequency chunks that can be gained within ST assignment. As mentioned earlier in each ST assignment period the negotiation is limited to a single cell pair. In the case of least satisfaction the amount of extra frequency chunks is the minimum requirement to carry the offered load in the selected cell pair. But in the latter case gain of extra frequency resources allows flexible deployment of frequency chunks reducing inter cell and inter RAN interference.

5. Conclusions

When considering the WINNER system deployments in metropolitan areas, this deliverable provides technical solutions (or accurate pointers for further work) with supporting performance assessment results for overcoming the major challenges in these kinds of environments

- For *spatial processing* (sections 3.2 and 4.2) in downlink different schemes for slowly moving users (like pedestrians) and fast moving users (users in cars or public transportation vehicles) were proposed. The precoded multiuser MIMO schemes proposed for slowly moving users are capable of providing very system throughput performance, as shown in section 4.2, while the adaptive linear dispersion codes proposed for fast moving users can provide the robustness required in their target case. When the performances of these different schemes are combined, it can be seen that in a typical dense urban case (more pedestrian and other slowly moving users than fast users), the spectral efficiency requirement set for the WINNER system downlink, i.e. 3 bits/Hz/cell, in [WIN2D6114]. In uplink the conclusion is that in metropolitan areas the utilization of multiple transmission antennas does not provide satisfactory gains, due to specific features of the propagation environment. There single antenna transmission (with antenna hopping) is proposed, combined with interference rejection combining receiver. This solution surpasses the set uplink spectral efficiency requirement [WIN2D6114], i.e. 1.5 bits/s/Hz.
- For *network synchronization* (sections 3.3 and 4.3) a novel, distributed, self-organizing method is proposed. Like the performance assessment results show this method can provide efficient and effective method for this task, which obviously can be utilized in order to optimize the performance of the whole system.
- *Relaying* (sections 3.4 and 4.4) is shown to be particularly beneficial in metropolitan area environments, which is also expected due to heavy blocking and shadowing of signals in these environments. It is shown that in metropolitan area deployments, utilization of relays can simultaneously offer higher system throughput and more cost efficient deployment. Cooperative relaying is shown to be especially suitable for metropolitan area system deployments, boosting the system performance even further.
- WINNER system concept covers both FDD and TDD modes. Sections 3.5 and 4.6 provide proof that the *multi-mode handovers* between FDD and TDD modes are possible and feasible, thus showing that the system is capable for flexible system operation and deployment.
- *Interference mitigation* (e.g. section 3.6) is an important topic in all wireless communication systems. In metropolitan areas this can be carried out by correct base station & relay node placement, proper resource partitioning between radio access points and within relay enhanced cells. As the number of interferers in downlink is very limited in metropolitan areas, advanced multiantenna receivers, like Interference Rejection Combining, will provide very good results in controlling the perceived interference level.
- *Spectrum technologies* (section 3.7 and 4.8), facilitating spectrum sharing and flexible spectrum use, can be in a very important position in future systems, increasing their flexibility in a significant manner. The results presented on short term spectrum assignment between two radio access networks show promising new ways to handle inter-system load balancing and interference levels.
- Other performance assessment results included in this deliverable are related to multi-use scheduling and MAC overhead reduction.
  - The scheduling results shown in section 4.5 concretely how sensitive the system performance is to the selected scheduler, and the parameters used. In the practical implementations of future systems, still a lot of research on this topic is required.
  - Overheads in e.g. control signalling and MAC, create significant issues and problems as they reduce the effective system throughput. Therefore solutions that efficiently reduce this overhead are very valuable from the system performance point-of-view. The Frame Descriptor Table based results presented in section 4.7 shown promising results in effectively reducing the MAC overhead in relay enhanced cell.

This deliverable has collect the system design and related performance assessment results in WINNER project targeting the system deployments in metropolitan areas. Together with the wide area and local area concept group deliverables [WIN2D61310] and [WIN2D61312], it provides the ”big picture” to the proposed technology components and solutions of WINNER system. Also, together these three deliverables provide broad and multifaceted view to the envisioned performance of WINNER system. A harmonized and consolidated view of these results will be presented in the WINNER system concept deliverable [WIN2D61314].

6. References

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7. Appendix

7.1 Inter-cell Interference Modelling in the Scheduling Strategies Investigation.

This section presents the strategy used in section 4.5 for interference modelling for the adaptive OFDMA downlink transmission in the Manhattan-like environment. Simultaneous simulation of hundreds of user terminals (UT) and over 70 base stations (BS) [ETSI1] would have prohibitive time and hardware requirements. The utilised strategy significantly reduces simulation time providing comparable system performance (in terms of the system capacity or users throughput).

7.1.1 Considered scenario and system setup

The considered scenario is the Metropolitan Area scenario with the street and buildings pattern specified by the Manhattan grid, presented in Figure 7-1. The considered area comprises 11×11 blocks divided by streets. The block length is specified to 200 m, and the street is 30 m wide. Base stations are situated over the streets between the intersections [WIN2D6137].

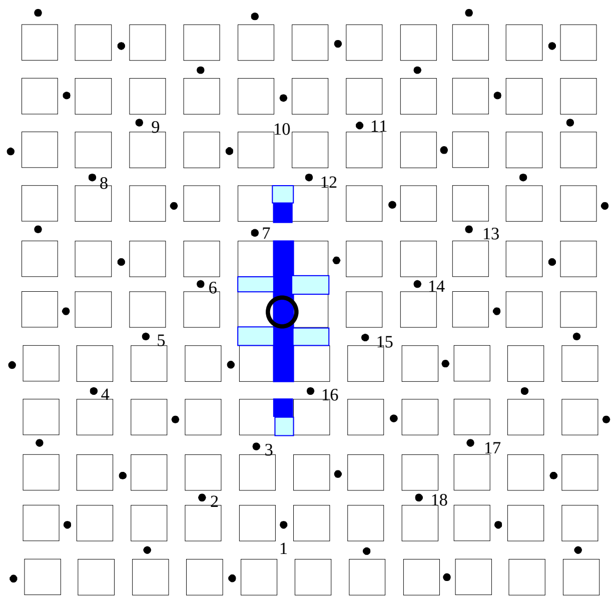

Figure 7-1: Considered Manhattan grid.

Outdoor-to-indoor transmission is not considered and all user terminals are uniformly distributed on the streets. Each UT is assigned to the BS offering the strongest signal at the UT location. The strength of the signal is calculated using path-loss models presented in [WIN1D54]. Terminals, which are located on the streets perpendicular to the street where the BS is located, experience NLOS transmission conditions. Additionally, system level simulations require the probability of line of sight for considered scenario for the BS and UT localised along the same street [WIN1D54]. An urban mobility model is assumed, with user terminals moving along streets and turning at cross streets with a given probability. Fast changing fading was not considered during assignment of the UTs to the BSs.

In the proposed scenario only one BS is considered (encircled in Figure 7-1. Propagation conditions and the developed path-loss models exclude any significant interference from the BSs localised on parallel streets and from the far-away BSs. In order to limit simulation time only, one entire microcell was considered and other microcells contributed only interferences. The area where practically all users were assigned to the central BS has been grayed in Figure 7-1. Darker shade marks the area where about 90% of users are assigned to the centrally located BS.

To minimise the number of interfering BSs required for the link level simulations in the microcellular environment different patterns of interfering BSs have been considered (BSs are numbered as presented in Figure 7-1), with 18 BS as the maximum number considered:

- 4_1 – interfering BS number 1, 6, 10, 15;
- 4_2 – interfering BS number 1, 7, 10, 16;
- 4_3 – interfering BS number 5, 6, 14, 15;
- 4_4 – interfering BS number 6, 7, 15, 16;
- 6_1 – interfering BS number 1, 5, 6, 10, 14, 15;
- 6_2 – interfering BS number 1, 6, 7, 10, 15, 16;
- 6_3 – interfering BS number 5, 6, 7, 14, 15, 16;
- 8_1 – interfering BS number 1, 5, 6, 7, 10, 14, 15, 16;
- 8_2 – interfering BS number 3, 5, 6, 7, 12, 14, 15, 16;
- 10_1 – interfering BS number 1, 3, 5, 6, 7, 10, 12, 14, 15, 16;
- 10_2 – interfering BS number 1, 4, 5, 6, 7, 10, 13, 14, 15, 16;
- 18 – interfering BS number 1 to 18;

The considered system setup was the downstream TDD adaptive OFDMA, with parameters specified in [WIN2D6137]. Very simple Round Robin scheduler assigned chunks to actually served users. In each superframe only 8 users were served, however in each snap-shot 40 different users were distributed within microcell. It was assumed that the positions of the UTs do not change during one superframe.

7.1.2 Results of the interfering BS pattern optimisation

The investigated parameters during simulations were the average total cell capacity and distribution of the mean throughput versus distance between the UT and the BS. The aim of the simulation was to reduce the number of interfering BSs while simultaneously preserving the reliable level of the interference, and thus reducing the computational complexity of the simulation.

Two methods of simulation were employed in order to evaluate required number and pattern of the interfering BS. In the first method the system level simulations were performed with the use of the modulation/coding – SINR curves for the convolutional codes instead of full physical layer simulation. For each scenario 50000 data frames were transmitted. The interferences were approximated as an additional AWGN with power equal to the power of all interfering signals. The second method was the full physical layer simulation, including time-domain channel filtering of both data and interfering signals. Due to the high computational complexity, only 500 data frames were transmitted for each scenario using the second simulation method.

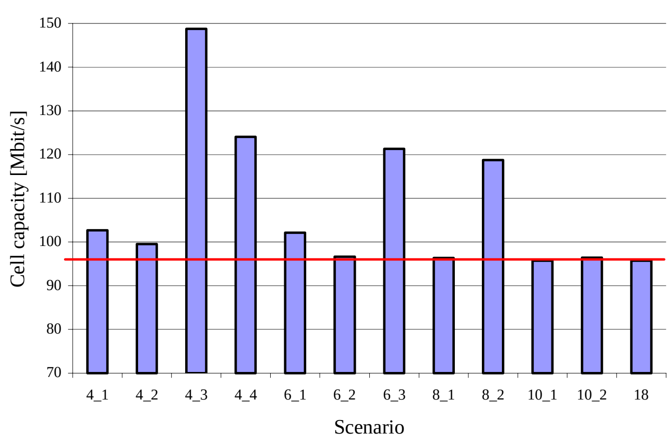

Figure 7-2: Total cell capacity depending on the chosen interference scenario for simplified simulation (convolutional coding).

Figure 7-4 presents the average total cell's capacity depending on the chosen interfering BS pattern for the first simulation method. The required reliable level of interference limits the total cell capacity to the value marked by the red line. In scenarios 18, 10_1, 10_2 and 8_1 and 6_2 the total cell capacity is approximately the same. However, the achieved total cell capacity can't be the only factor in evaluation of the interference level. It is required to analyse the average throughput achieved by each scheduled user depending on its distance to the BS, presented in Figure 7-3.

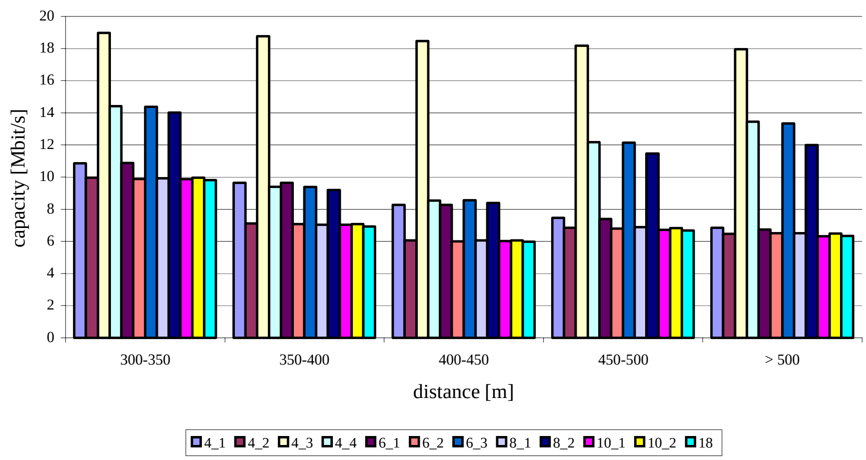

Figure 7-3: Average user's throughput depending on the distance between BS and UT for simplified simulation (convolutional coding).

It can be observed that for the patterns 10_2, 8_1 and 6_2, considered sufficient for interference simulation so far, the mean throughput is slightly higher than in case of 18 interfering BS. However, for 10 interfering BS specified as in pattern 10_1, the mean transmit capacity is approximately the same as for 18 interfering BSs, hence the pattern 10_1 is sufficient to accurately model the inter-cell interference.

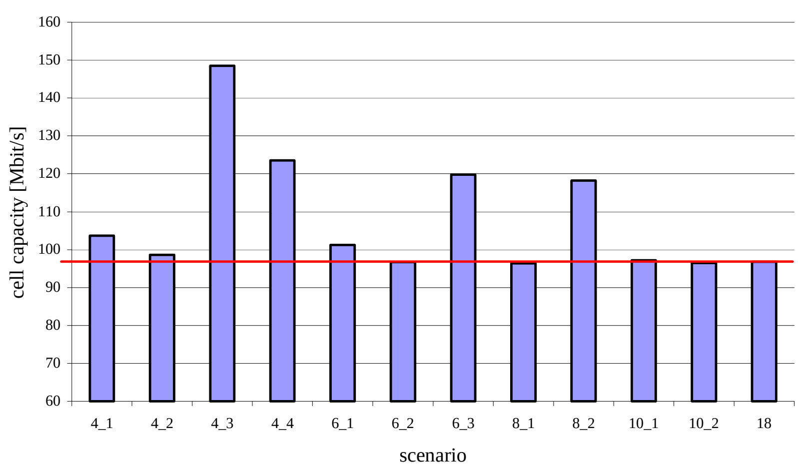

Figure 7-4: Average total cell capacity depending on the chosen interference scenario for full simulation (convolutional coding).

Similar comparison was performed for the full physical layer simulation. Figure 7-4 presents the total cell capacity depending on the selected interfering BSs' pattern. Similar total cell capacity can be observed in scenarios 18, 10_1, 10_2, 8_1 and 6_2, as for simplified simulation model. Analysing the average throughput achieved by each scheduled user depending on its distance to the BS, presented in Figure 7-5, the previous observations are confirmed. Minor variations of the achieved throughput between the considered so far sufficient patterns may be observed due to the shorter simulation run (500 data frames comparing to the 50000 data frames for the simplified simulations).

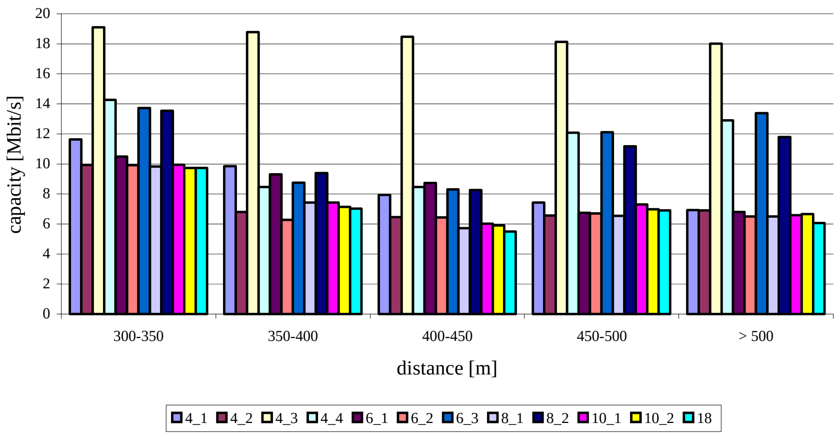

Figure 7-5: Average user's throughput depending on the distance for full simulation (convolutional coding).

The conclusion is that the most significant disturbers are these, which are localised on the same street as the UT and LOS propagation of interferences is possible (e.g. BS number 1 and 10). Secondary source of interferences are BSs localised "just behind the corner", like BS number 3 or 16. Generally other BSs, such as 3, 5, 6, 7, 12, 14, 15, and 16 are localised close enough to have substantial influence on the interference level and may be necessary to accurately simulate the interference between neighbouring cells in the Manhattan environment.

There is no difference in results between simulation with the proposed BS pattern (the 10_1 pattern) and other scenarios, such as with 18 or more interfering BS. That is why simulation results obtained for even larger number of interfering BS (up to 26) were not included. Hence, for the purposes of further simulations only 10 interfering BSs are required, placed as specified in pattern 10_1.

7.2 Handover Performance with Relay-Enhanced Cells: Background

7.2.1 Simulation assumptions

The multi-mode capability of the MAC protocol investigated in Section 4.6 is evaluated by simulation investigations of the delay, throughput and handover durations in different handover scenarios. General simulation parameters are listed in Table 7-1. They are consistent with the assumptions defined in [WIN2D6137].

Parameter	Value	Unit	Comment
Antenna type	omni-directional		
Channel model BS↔RN	B5C		see [WIN2D6137]
Channel model RAP↔UT	C2NLOS		see [WIN2D6137]
Power control	None		
Number of UTs	1		
Mobility	3	m/s	
Distribution of packet inter arrival time	Poisson		
Packet size	1024	Bit	Fixed
DL traffic rate above IP	5	Mbit/s	
UL traffic rate above IP	5	Mbit/s	
MCS preamble	BPSK 1/2		No link adaptation
Simulation time	1400	s	
Number of handovers	209		
Symbols per resource allocation table	1		
Chunks per frame	2		
Frames per super-frame	8		
Frame length	0.6912	ms	
Preamble duration	0.36	ms	
Super-frame length	5.8896	ms	

Table 7-1: General simulation parameters.

Specific parameters for the two considered modes FDD and TDD are listed in Table 7-2 and Table 7-3, respectively.

Parameter	Value	Unit	Comment
Duplex scheme	FDD		
Multiplexing scheme	TDMA/OFDMA		
Mid frequency	4.2 (UL) 4.45 (DL)	GHz GHz	Changed compared to [WIN2D6137] see section 4
Signal bandwidth	2 x 45	MHz	
Symbols per chunk (symbols x subcarriers)	11 x 8 = 88		First symbol in DL used for resource allocation table and in UL unused
Used subcarriers	1152		
Subbands	144		
OFDMA symbol duration	28.8	µs	
Transmitting power (fixed per subband)	24.416 15.416 2.416	dBm dBm dBm	BS, total of 46 dBm RN, total of 37 dBm UT, total of 24 dBm

Table 7-2: FDD specific parameters.

Parameter	Value	Unit	Comment
Duplex scheme	TDD		
Multiplexing scheme	TDMA/OFDMA		
Mid frequency	3.95	GHz	
Signal bandwidth	89.84	MHz	

Symbols per chunk in DL (symbols x subcarriers)	14 x 8 =112		First symbol in DL used for resource allocation table
Symbols per chunk in UL (symbols x subcarriers)	15 x 8 = 120		
Used subcarriers	1840		
Subbands	230		
OFDMA symbol duration	22.48	µs	
Transmitting power (fixed per subband)	13.382 6.382 0.382	dBm dBm dBm	BS, total of 37 dBm RN, total of 30 dBm UT, total of 24 dBm
Duplex guard time	8.4	µs	Incl. cyclic prefix

Table 7-3: TDD specific parameters.