SHARING

SELF-ORGANIZED HETEROGENEOUS ADVANCED RADIO NETWORKS GENERATION

D2.2

Scenarios, KPIs and Evaluation Methodology for Advanced Cellular Systems

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Abstract:

This document defines the project scenarios, identifies the relevant KPIs and defines the evaluation methodologies to be used by the innovation WPs of the project (WP3, WP4 and WP5).

Nine deployment scenarios for future radio access networks have been defined and will be addressed in the project : 1-LTE macro cell only, 2-LTE small cell only, 3-LTE HetNet (LTE macro + LTE micro/pico/femto), 4-Inter-RAT HetNet (LTE + WiFi), 5-Relays, 6-Device-to-Device (D2D), 7-Carrier Aggregation (CA), 8-HSPA, 9-Generic multi-cell/Technology agnostic. Each deployment scenario contains several use cases whose specific characteristics have been presented in detail. An extensive KPI analysis has been made and a set of relevant KPIs as well as evaluation methodologies have been identified and described for each use case.

The deliverable will serve as a guideline for the technical work which will be carried out in the innovation WPs of SHARING.

Keywords: Scenarios, KPIs, evaluation methodology

Document Revision History

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0.1	20/9/2013	Frederic Pujol (IDATE)	Creation of the Table of Contents (ToC)
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0.3	29/11/2013	Berna Sayrac (FT)	Preliminary input on scenarios FT
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0.26	28/01/2014	Frederic Pujol (IDATE)	Integration of modifications in KPI section
0.27 Final version	31/12/2014	Berna Sayrac (FT)	Final review of the document

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EXECUTIVE SUMMARY

This deliverable D2.2 “Scenarios, KPIs and evaluation methodology for advanced cellular systems” presents the outcome of the following tasks in WP2:

- Task 2.1.1 - Scenarios and Market analysis (Task Leader: IDATE). The scenarios are part of D2.2 but the market analysis will be presented in deliverable D2.5
- Task 2.1.2 - KPIs and Evaluation Methodology (Task Leader: FT)

The contents of this deliverable will be used as a basis for further work in WP2 (market analysis, global project concepts etc.) as well as for WP3, WP4 and WP5.

The objective of this deliverable is three-fold: 1-it defines the project scenarios on radio access technologies of today and the near future, 2-it presents a thorough KPI analysis and identifies relevant KPIs for the scenarios, and 3-it describes the appropriate evaluation methodologies in assessing the performances of the project scenarios in terms of the identified KPIs.

Future internet should be characterized by an important volume of traffic and a huge disparity in throughput, latency, mobility requirements, influenced by the growth of cloud computing, internet of service and internet of things; but also the societal evolution toward social networking and sharing of any content; or new global challenges like the target for energy-efficiency. The project scenarios in this deliverable have been defined based on this vision.

Considering possible evolution paths and enhancements for future radio access networks, the following deployment scenarios have been defined:

1. Deployment scenario 1: LTE macro cell only
2. Deployment scenario 2: LTE small cell only
3. Deployment scenario 3: LTE HetNet (LTE macro + LTE micro/pico/femto)
4. Deployment scenario 4: Inter-RAT HetNet (LTE + WiFi)
5. Deployment scenario 5: Relays
6. Deployment scenario 6: Device-to-Device (D2D)
7. Deployment scenario 7: Carrier Aggregation (CA)
8. Deployment scenario 8: HSPA
9. Deployment scenario 9: Generic multi-cell/Technology agnostic

These 9 deployment scenarios represent various deployment alternatives with different features for LTE-A and evolutions beyond LTE-A. Each deployment scenario contains several scenarios and each scenario corresponds to an innovation which will be studied (designed and evaluated) by one or several project partners. The outcome of these studies within each deployment scenario is expected to yield the overall expected benefits and drawbacks of that deployment scenario in terms of the identified KPIs and through the evaluation methodologies presented in this deliverable. Thus, we will be able to: 1-draw some general conclusions on each deployment scenario, 2-compare the relative tendencies in terms of performance, capacity and complexity; and finally 3-come up with recommendations to the operators on the pros-and-cons of each deployment choice for future radio access networks.

In order to present the scenarios as uniform as possible, the scenarios within each deployment scenario have been described in detail with the same set of characteristics/parameters (where applicable) which are put in a tabular form. Relevant KPIs and the appropriate evaluation methodology for each scenario are also presented and summarized in this deliverable.

1 Introduction

This deliverable D2.2 "Scenarios, KPIs and evaluation methodology for advanced cellular systems" presents the project scenarios, the relevant KPIs and the associated evaluation methodologies as the outcome of the following tasks in WP2:

- Task 2.1.1 - Scenarios and Market analysis (Task Leader: IDATE). The scenarios are part of D2.2 but the market analysis will be presented in deliverable D2.5
- Task 2.1.2 - KPIs and Evaluation Methodology (Task Leader: FT)

The project scenarios are presented as a set of 9 deployment scenarios where a deployment scenario implies distinct network features and deployment characteristics. Each deployment scenario comprises of several scenarios and each scenario corresponds to an innovation which will be studied (designed and evaluated) by one or several project partners. Such a structure allows us to asses the overall expected benefits and drawbacks of every deployment scenario in terms of the identified KPIs and through the evaluation methodologies presented in this deliverable. Thus, we will be able to: 1-draw some general conclusions on each deployment scenario, 2-compare the relative tendencies in terms of performance, capacity and complexity; and finally 3-come up with recommendations to the operators on the pros-and-cons of each deployment choice for future radio access networks.

Objective and structure of the document

The objective of this deliverable is three-fold: 1-it defines the project scenarios on radio access technologies of today and the near future, 2-it presents a thorough KPI analysis and identifies relevant KPIs for the scenarios, and 3-it describes the appropriate evaluation methodologies in assessing the performances of the project scenarios in terms of the identified KPIs. The contents of this deliverable will be used as a basis for further work in WP2 (market analysis, global project concepts etc.) as well as for WP3, WP4 and WP5.

Considering possible evolution paths and enhancements for future radio access networks, the following deployment scenarios have been defined:

1. Deployment scenario 1: LTE macro cell only
2. Deployment scenario 2: LTE small cell only
3. Deployment scenario 3: LTE HetNet (LTE macro + LTE micro/pico/femto)
4. Deployment scenario 4: Inter-RAT HetNet (LTE + WiFi)
5. Deployment scenario 5: Relays
6. Deployment scenario 6: Device-to-Device (D2D)
7. Deployment scenario 7: Carrier Aggregation (CA)
8. Deployment scenario 8: HSPA
9. Deployment scenario 9: Generic multi-cell/Technology agnostic

The deliverable is organized to give a detailed presentation of the above 9 deployment scenarios, followed by a thorough KPI analysis, and the description of the associated evaluation methodologies. For uniformity purposes, the scenarios are presented using a template which contains a relevant set of aspects/characteristics/parameters for all scenarios.

2 Definition of project scenarios

This section describes in detail the project scenarios. As mentioned above, the 9 main deployment scenarios contain individual scenarios, each of which will be studied by one or more partners. The 9 deployment scenarios will allow us to come up with conclusions/comparisons on different deployment strategies for (near) future networks, i.e. which deployment has advantages/disadvantages under which conditions and according to which KPIs.

In order to present the scenarios as uniform as possible, the scenarios within each deployment scenario have been described in detail with the same set of aspects/characteristics/parameters (where applicable) in a tabular form. Below, you can see the list of these aspects/characteristics/parameters together with their short descriptions:

- **Scenario title:** The name of the scenario.
- **Task:** The project task in which the associated innovation is found.
- **Network topology:** The types of the radio access nodes in the network, such as macro cell only (only high-power nodes), small cell only (only low power nodes), HetNet (overlay of macro cells and small cells), multi-cell (any type of BS, could be high- or low-power).
- **Radio Access Technology (-ies):** The specific radio access technology/technologies which are used in the scenario, such as: HSPA, LTE(-A), Wi-Fi (or WLAN) or co-existence of two or more of these RATs.
- **Nature of small cells:** What type(s) of small cells is/are present in the scenario (if there are any small cells)? Examples are LTE(-A) pico/micro/femto cells, Wi-Fi access points or the co-existence of two or more of these nodes.
- **Environment:** The type of generic environment in which the evaluations are performed, such as dense urban, urban, suburban, rural etc. Also, more specific environment types, such as shopping center, university campus, train station, offices, homes/flats etc. can be considered.
- **Context:** The context in which the evaluations are performed, such as outdoor, indoor, in-vehicle etc.
- **Inter-site distance (ISD):** If applicable, the distance between several different types of nodes (macro, small cell, relay, UE etc.)
- **Frequency deployment strategy:** If applicable, an indication whether different nodes use different or the same frequency band/channel/carrier frequency. The former is called as separate channel deployment or frequency reuse greater than 1 whereas the latter is known as co-channel deployment or frequency reuse 1). There is also the possibility of having different carriers combined in a Carrier Aggregation (CA) scheme.
- **Frequency bands:** If applicable, which specific frequency bands are used in the scenario? Examples are LTE licensed bands, HSPA licensed bands, Wi-Fi unlicensed bands (2.4G or 5G), TV whitespaces or combinations of these.
- **Density of small cells:** If applicable, what is the density of the small cells? Ex: Dense (more than 2 per macro) or sparse?
- **Backhaul:** If applicable, the assumptions on the capacity of the backhaul(s) used in the scenario. Can be ideal (no latency, infinite capacity) OR non-ideal backhaul (for ex. X2 interface). The considered backhauls are between different types of nodes involved in the scenario (macro cells, small cells, relays, core network nodes etc.).
- **Propagation/channel model:** Which type of channel model is used in performance evaluation of the scenario? Here, a vide possibility of choices are possible, depending on the type of performance evaluations. Typical examples are path-loss models (statistical, ray-tracing etc.), shadowing characteristics, fast fading etc.
- **Mobility model:** If applicable, which type of mobility is used in evaluating the performance of the scenario? Typical examples are percentages of users moving at typical speeds (nomad/static users, pedestrians at 3 km/hr, in-vehicle users at 50 km/hr etc.
- **Traffic model:** If applicable, which type of traffic model is used in scenario evaluations? Typically Poisson arrivals are assumed with a fixed/pre-determined arrival rate and a fixed average service time. Different parameters (arrival rate and service time) can be assumed for non-homogeneous traffic (background traffic with hot-spots). Besides, constant (stationary) or time-varying (non-stationary) traffic characteristics are also considered.

- **<u>Services:</u>** If relevant, the services considered in the scenario, such as voice (VoIP), data (file download, web browsing, audio/video streaming etc.). A mixture of different services can be defined with certain percentages for each type of service. Also, the QoS requirements for each type of service are also of concern.
- **<u>Number of transmit/receive antennas (for MIMO schemes):</u>** If the scenario uses multiple antenna schemes, what are the number of transmit and receive antennas used?
- **<u>KPIs, metrics involved:</u>** What are the metrics/KPIs which will be used to evaluate the scenario? Here, as in the case of propagation channel models, a wide list exists. The used metrics/KPIs depend on the type/method of performance evaluations used. For link-level (PHY) evaluations, typical examples are Sum Rate, Bit Error Rate, Frame Error Rate, average link throughput etc. For system-level evaluations, typical examples are Avg. Cell Throughput, Block Call Rate, File Transfer Time, Latency etc. The choices and types of KPIs are thoroughly elaborated in section 3 of this document.
- **<u>Description of the problem to be solved (target) and proposed method for solution:</u>** A short description of the objective of the scenario and the innovation involved. For ex. maximizing sum rate (small cells + macro cells) through cell cooperation (CoMP), minimizing total energy consumed by macro cells and small cells through intelligent cell switch ON/OFF schemes, maximizing carried network traffic through intelligent Wi-Fi offloading mechanisms, developing realistic propagation models for base station-to-relay channels through ray tracing methods etc. Detailed descriptions of the scenarios are given in section 2 of this deliverable.
- **<u>Evaluation method:</u>** Which type of evaluation method will be used for the scenario? As mentioned above, the evaluation methodology depends on the type/nature of the evaluation (link/PHY or system level) and determines the metrics/KPIs. For link-level (PHY) evaluations, link level simulations are performed. These are small scale Monte-Carlo simulations (in the order of 1 ms or even below) where only the PHY (sometimes MAC) layer protocols are simulated. For system-level evaluations, system-level simulations are performed. These are medium- to large-scale Monte Carlo simulations (in the order of at least 1s typically) where MAC and above protocols (user arrivals/departures, mobility etc.) are simulated. Apart from those, there are also analytical/theoretical evaluation methodologies. These types of methods provide evaluations from an Information Theoretic perspective (typically capacity evaluations), PHY perspective (error rates, outage probabilities) or flow-level analysis (based on Queuing Theory). In general, such type of theoretical evaluations yield upper/lower bounds on performance in terms of link-level (PHY) metrics/KPIs. More elaboration on evaluation methods is given in section 4 of this deliverable.

Note that:

1- When there is a NA in any one of the above fields, it means that the characteristic/aspect is not relevant, i.e. not used in the study. This is often the case for theoretical studies where the analysis is made for a generic radio access system, without a specific RAT, topology, environment etc.

2- The characteristics/aspects are given according to the results which will be provided within the technical work carried out in the other WPs. ***Although most of the of the techniques proposed within the scenarios are applicable to a variety of technologies, topologies, layouts, environments, context, mobility/traffic types, channel models etc., only those with which performance evaluation results will be provided are considered in this document and depicted in the tables.***

3- The possible links between each scenario and other WPs are also indicated at the bottom of the tables.

2.1 Deployment scenario 1: LTE macro cell only

Deployment scenario 1 gathers the following 7 scenarios involving only LTE macro cells:

1. Mobility Load Balancing (MLB) in LTE macro cell networks
2. Load Balancing (LB) via transmit power optimization in LTE macro cell networks
3. Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks
4. Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks
5. Interference reduction in LTE through link level processing
6. Multipoint Coordination Schemes for LTE-Advanced Networks
7. Joint Processing CoMP algorithm, combined with interference cancellation at the receiver

2.1.1 Mobility Load Balancing (MLB) in LTE macro cell networks

This scenario will evaluate the performance of user mobility parametric changes for load balancing in LTE macro cell networks. Intra-LTE MLB consists of tuning the outgoing Handover Margin (HM) parameter of the handover procedure as defined by event A3 for LTE[1].

The scenario will consist of a loaded (hotspot) cell surrounded by a group of unloaded cells (cf. Figure 1) and a certain user mobility which will allow the users to move between the cells. Changes to HM will dictate if the mobile user handover will be preponed or postponed thereby affecting other Key Performance Indicators (KPIs) of the individual cells such as Block Call Rate (BCR), Drop Call Rate (DCR), and Throughput.

This scenario allows us to 1- Study the impact of HM on user mobility, 2- Evaluate KPIs as a function of HM. 3- Develop a HM self-optimization framework for load balancing using statistical learning techniques. A system level simulator using only downlink transmissions, which performs correlated snapshots of users arrival, establish communication to download a file, mobility and departure on call termination will be used.

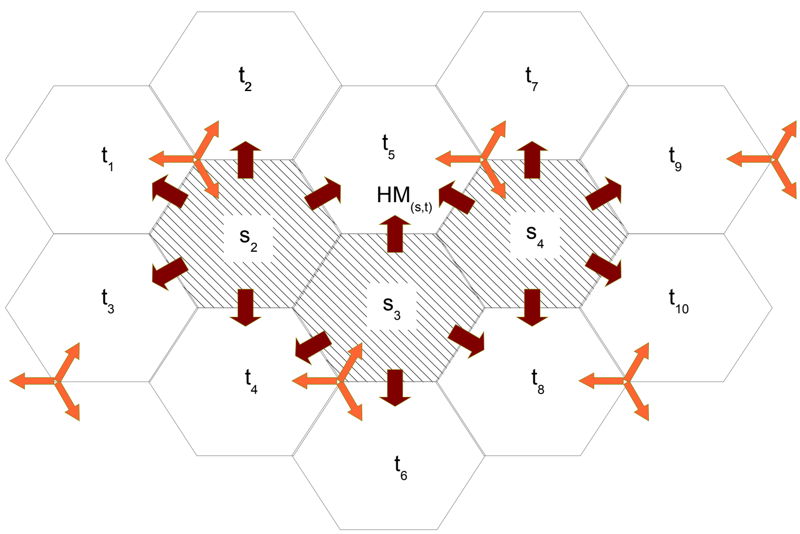


Figure 1: MLB scenario with red arrows indicating outgoing handovers

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Mobility Load Balancing (MLB) in LTE macro cell networks
Task	T4.1
Network topology	Macro cells only
Radio Access Technology (-ies)	LTE
Nature of small cells	No small cells
Environment	(Sub-)urban
Context	Outdoor
Inter-site distance	500 meters (macro-to-macro)
Frequency deployment strategy	Co-channel deployment*
Frequency bands	LTE licensed bands
Density of small cells	No small cells
Backhaul	Ideal backhaul
Propagation/channel model	Path loss: 128.1+37.6log10(R), R in Km (3GPP Model 1, TR 36.814) Lognormal shadowing standard deviation: 6 dB
Mobility model	90% of users at 30 km/hr 10% of users static
Traffic model	Poisson arrivals with arrival rate of 2.4 users/second and avg. service time of 3 seconds with a spatial traffic distribution of 50% users in Hotspot
Services	Data: 100% of users FTP (file size = 8 MB)
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Drop Call Rate, Load, File Transfer Time, Cell Edge Throughput, Cell Center Throughput
Description of the problem to be solved (target) and proposed method for solution	Mobility load balancing: 1. Minimizing mean squared difference of cell loads to balance cell loads and minimize interference between neighboring cells. 2. Use of surrogate based iterative self-optimization procedures to achieve the above objectives.
Evaluation method	System level simulations

Links with other work packages: none

* Co-channel deployment in macro configuration means single carrier

2.1.2 Load Balancing (LB) via transmit power optimization in LTE macro cell networks

This scenario evaluates the performance of load balancing algorithm via transmit power optimization in LTE macro deployment scenario. So far, studies on optimization performance evaluation for load balancing solutions that are based on transmit power optimization have not been carried out.

Via this scenario, the impact of capacity in a well-covered network and the influence of transmit powers on network KPIs with the relative drawbacks/advantages will be studied extensively. The scenario involves a central hotspot zone (G_1) surrounded by a regular traffic zone (G_2) (c.f. Figure 2). The eNBs in the two zones can adjust their transmit powers to alter the extent of their coverage, thereby forcing users to get handed over between the neighboring cells and improving/degrading the Quality-of-Service in the respective regions. The second busiest hour data from a daily traffic pattern which is extracted from an operational network will be used for simulations.

The scenario will allow us to 1- understand the mutual interactions between the eNBs to reduce overall network inter-cell interference. 2- understand the impact of transmit power changes on network KPIs such as Load, Block call Rate (BCR), File Transfer Time (FTT), 3- develop and evaluate a transmit power based iterative self-optimization framework for load balancing and 4- evaluate and compare the performance of using the second-busiest-hour optimized transmit power settings to daily traffic pattern.

In order to achieve these goals, flow level system simulations will be used.

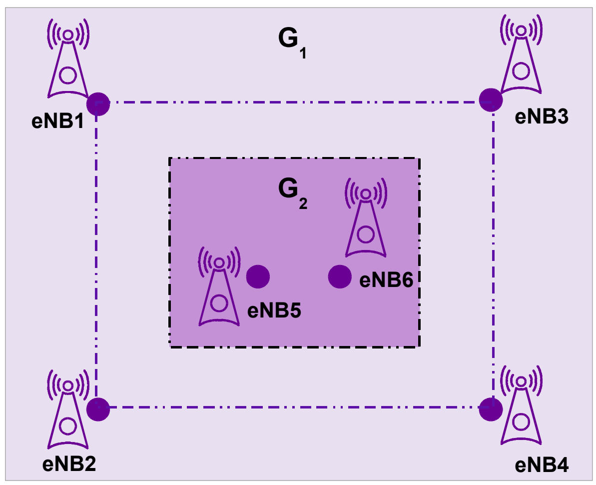


Figure 2: Transmission power based load balancing scenario (G_2 hotspot zone)

The details of the scenario are summarized in the table below:

Scenario aspect	Description
Title	Load Balancing (LB) via transmit power optimization in LTE macro cell networks
Task	T4.1
Network topology	Macro cells only
Radio Access Technology (-ies)	LTE
Nature of small cells	No small cells
Environment	(Sub-)Urban
Context	Outdoor
Inter-site distance	900 meters macro to macro in zone G_1, 300 meters macro to macro in zone G_2
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	No small cells
Backhaul	Ideal backhaul
Propagation/channel model	Path loss: 128.1+37.6log10(R), R in Km (3GPP Model 1, TR 36.814) Lognormal shadowing standard deviation: 6 dB
Mobility model	No mobility
Traffic model	Poisson arrivals with constant average arrival rate λ and constant average service time μ.
Services	Data: 100% of users FTP (file size = 10 MB)
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Load, File Transfer Time
Description of the problem to be solved (target) and proposed method for solution	Transmission power based load balancing: 1. Minimizing maximum of cell loads to balance cell loads and minimize interference between neighboring cells. 2. Use of surrogate based iterative self-optimization procedures to achieve the above objectives.
Evaluation method	Flow level system simulations[2]

Links with other work packages: none

2.1.3 Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks

This scenario evaluates the performance of capacity improvements/changes by changing the antenna tilts of individual eNBs in LTE macro cell network actively i.e. wherein the elements of the antenna are electronically adjusted thereby varying the beam characteristics in terms of azimuth and/elevation. So far studies on the tilt based performance evaluation of capacity and/or coverage self-optimization has been carried out only using the Remote Electrical Tilts (RETs) of the passive antennas.

The scenario will involve a cluster of *Target* cells (c.f.Figure 3) with irregular traffic density and the tilts θ of each of which can be varied to evaluate the effect on network KPIs. This will be surrounded by a group of *Observation* cells whose KPIs will be monitored along with the KPIs of the target cells.

The scenario allows us to 1- define a set of KPIs each of which will either jointly or independently provide insight into the cell-to-cell tilt based interactions 2- fully understand the effect of antenna tilt changes in target cells on the KPIs of the target and/or observation cells with respect to capacity/coverage and inter-cell interferences. 3-define and evaluate a generic iterative self-optimization framework based on stochastic approximation for optimizing any individual/joint KPI.

Simulations will be carried out for downlink only using a system level simulator without considering user mobility.

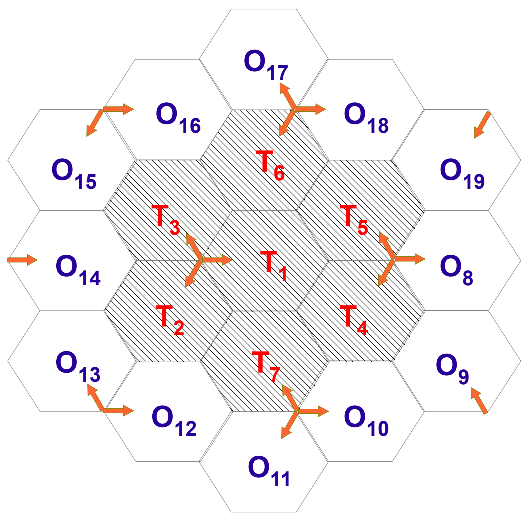


Figure 3: AAS based optimization with the optimization zone (T) and the observation zone (O)

The details of the scenario are summarized in the table below:

Scenario aspect	Description
Title	Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks
Task	T4.1
Network topology	Macro cells only
Radio Access Technology (-ies)	LTE
Nature of small cells	No small cells
Environment	(Sub-)urban
Context	Outdoor
Inter-site distance	500 meters for macro-to-macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	No small cells
Backhaul	Ideal backhaul
Propagation/channel model	Macro to UE: 128.1+37.6log10(R[km]) Pico to UE: 140.7+36.7log10(R[km])]) (3GPP Model 1, TR 36.814) Lognormal shadowing standard deviation: 6 dB
Mobility model	No mobility
Traffic model	Poisson arrivals with constant average arrival rate λ and constant average service time μ.
Services	Data: 100% of users FTP (file size = 10 MB)
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Cell Edge Throughput, Cell Center Throughput, Load, File Transfer Time for both Target and Observational cells
Description of the problem to be solved (target) and proposed method for solution	Antenna tilt optimization for capacity enhancement: 1. Maximizing sum of cell edge throughput and sum of cell center throughputs of target cells under constraints on Block Call Rate. 2. Minimizing the maximum of cell loads of target cells under constraints on Block Call Rate. 3. Minimizing the sum of File Transfer Times of all target cells under constraints on Block Call Rate. 4. Use of surrogate based iterative self-optimization procedures to achieve the above objectives.
Evaluation method	System level simulations[3]

Links with other work packages: none

2.1.4 Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks

This scenario evaluates the performance of most common multi-cell cooperation schemes (i.e. CoMP schemes) in LTE macro cell networks in a cross-layer manner, i.e. taking into account higher layer phenomena, particularly Radio Resource Control (RRC) or Radio Resource Management (RRM) processes such as user mobility. So far, studies on performance evaluation of the existing CoMP solutions have been done exclusively in a PHY/MAC context, using only PHY/MAC layer models and discarding the effects of RRC/RRM procedures. This situation prevents us to fully know the benefits/drawbacks of such solutions when deployed on real networks where User Equipment (UE) move and their mobility/conditions are impacted by RRM/RRC procedures (cf. Figure 4). Hence, this scenario allows us to: 1-fully understand the interactions between the PHY/MAC and RRC/RRM aspects in the existing CoMP solutions; and 2-have a more realistic performance evaluation of those solutions from a system level point of view. In order to achieve these goals, new cross-layer models and performance evaluation methods will be developed, verified by realistic system-level simulations.

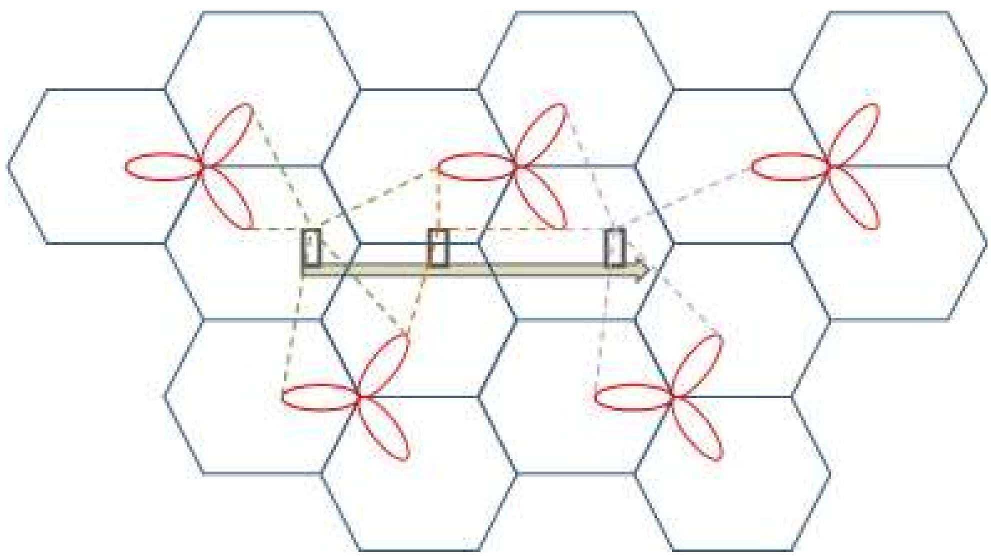


Figure 4: User mobility within a macro cell CoMP scheme

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks
Task	T3.1
Network topology	Macro cells only
Radio Access Technology (-ies)	LTE
Nature of small cells	No small cells
Environment	Urban/Dense urban/Rural
Context	Outdoor
Inter-site distance	500-2000 meters
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	No small cells
Backhaul	Ideal backhaul
Propagation/channel model	3GPP channel models[4]
Mobility model	Random motion of users with: – a mix of varying speeds between 0-30 km/hr – 3GPP mobility settings[5]
Traffic model	Elastic traffic of Poisson arrivals with constant average arrival rate λ and constant average service time μ.
Services	Data service: file download of a fixed file size
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Cell Loads, File Transfer Time, Throughput, Capacity.
Description of the problem to be solved (target) and proposed method for solution	Performance evaluation of the existing CoMP schemes taking into account RRM/RRC processes such as user mobility. Cross-layer model development based on queuing theory, validated by system-level simulations.
Evaluation method	Cross-layer models based on queuing theory and system-level simulations.

Links with other work packages: none

2.1.5 Interference reduction in LTE through link level processing

This scenario will study PHY layer transmitter-side solutions on:

- interference suppression or avoidance with advanced MIMO schemes taking care of performance and implementation feasibility in single-cell multi-user configurations, and
- advanced interference mitigation in the uplink, with optimization of the reception and interference rejection techniques in the uplink, for single carrier waveform and frequency domain equalization.

The focus will be in open loop schemes for an improvement of the budget link and for mitigating interferences. The main investigation track will be on linear dispersive spatio-temporal codes, which generates transmitted signals with non-circular statistics. With this kind of signals, widely linear receiver schemes may be used to efficiently suppress or mitigate interference.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Interference reduction in LTE through link level processing
Task	T3.1 and T3.2
Network topology	Macro cell only
Radio Access Technology (-ies)	LTE-A
Nature of small cells	NA
Environment	(Sub-)urban
Context	Both Outdoor and Indoor
Inter-site distance	Few kms for macro-to-macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	NA
Backhaul	Ideal backhaul between macro cells
Propagation/channel model	Path loss: Winner 2D model Shadowing: Winner 2D model Fast fading: Rayleigh
Mobility model	100% of pedestrians users, or 100% of vehicular users
Traffic model	Full buffer constant traffic for PHY simulations
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	2x1 or 2x2 or 4x1 or 4x2
KPIs, metrics involved	Bit Error Rate
Description of the problem to be solved (target) and proposed method for solution	Maximizing sum rate through interference mitigation techniques
Evaluation method	Analytical Link level simulations

Links with other work packages: none

2.1.6 Multipoint Coordination Schemes for LTE-Advanced Networks

This scenario considers the definition and performance evaluation of an efficient scheduling method for multipoint coordination schemes (CoMP) in LTE-A and beyond. CoMP requires close coordination between several eNBs. In a near future scenario, no-CoMP users will co-exist with CoMP users (i.e. users having the opportunity to use the CoMP feature). Therefore, the same eNB schedulers must manage CoMP as well as no-COMP users with fairness. This scenario will investigate fair scheduling schemes which handle this co-existence. The system performance will be evaluated by a system simulator and compared to a no-COMP system. We will also treat the impact of the backhaul imperfection and of the feedback latency on each proposed scheduler.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Multipoint Coordination Schemes for LTE-Advanced Networks
Task	T3.1
Network topology	Macro cells only
Radio Access Technology (-ies)	LTE-A
Nature of small cells	No small cells
Environment	Dense urban, Urban, Suburban and Rural
Context	Outdoor
Inter-site distance	500, 1 732 and 1 299 m for macro-to-macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	No small cells
Backhaul	Ideal backhaul
Propagation/channel model	Compliant to ITU-R M.2135-1
Mobility model	3,30, 90 and 120km/h as specified by ITU-R M.2135-1
Traffic model	Full buffer and TUDR
Services	Voice and Data: 100% of users FTP
Number of transmit/receive antennas (for MIMO schemes)	MIMO
KPIs, metrics involved	Avg. cell throughput
Description of the problem to be solved (target) and proposed method for solution	Maximizing sum rate (macro cells) through cell cooperation (CoMP)
Evaluation method	System level simulations

Links with other work packages: none

2.1.7 Joint Processing CoMP algorithm, combined with interference cancellation at the receiver

In this scenario, two adjacent cells with multi-antenna eNBs cooperate in a CoMP Joint Processing (JP) scheme, at least for cell edge users. A MU-MIMO scheme is used in at least one cell in order to compensate for the incurred loss of resource due to JP CoMP. However, whatever codebook may be used at the eNB, the UE will still experience some residual interference due to paired UEs of the MU-MIMO scheme. Therefore, a CoMP UE should be equipped with an interference cancellation receiver. The goal is to evaluate the performance of such a combined DL scheme: CoMP with MU-MIMO, combined with interference cancellation at the UE receiver.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	JP CoMP algorithm, combined with interference cancellation at the receiver
Task	T3.1
Network topology	Macro cell only
Radio Access Technology (-ies)	LTE-A
Nature of small cells	NA
Environment	(Sub)-urban
Context	Outdoor
Inter-site distance	500 or 1732 meters for macro-to-macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	NA
Backhaul	Ideal backhaul
Propagation/channel model	Spatial Channel Model Extended (SCME)
Mobility model	Spatial Channel Model Extended (SCME)
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	{2 or 4} / 2
KPIs, metrics involved	Bit Error Rate Packet Error Rate
Description of the problem to be solved (target) and proposed method for solution	In a CoMP MU MIMO scenario, implement an interference cancellation scheme at the receiver
Evaluation method	Link level simulations

Links with other work packages: none

2.2 Deployment scenario 2: LTE small cells only

Deployment scenario 2 gathers the following 2 scenarios involving only LTE small cells:

1. Dynamic UL/DL Duplexing for TDD-enabled Small Cells
2. ON/OFF power saving in campus of small cells

2.2.1 Dynamic UL/DL Duplexing for TDD-enabled Small Cells

This scenario considers the flexible and dynamic UL and DL switching in TDD-enabled small cells. Due to the traffic asymmetry in small cells, there is a need to optimize the switching point[†] locally taking into account various key parameters such as interference levels, file size, latency, and small cell density. Other interesting aspects related to the UL/DL switching point entail clustering among locally coupled small cells, power control and other interference management techniques.

The proposed algorithm is self-organizing such that decisions are taken locally at the small cells as a function of the traffic load and interference levels at both DL and UL.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Dynamic UL/DL duplexing for TDD-enabled small cells
Task	T4.1
Network topology	Outdoor pico
Radio Access Technology (-ies)	LTE(-A)
Nature of small cells	LTE pico
Environment	Urban
Context	Both outdoor and indoor areas (evaluation area)
Inter-site distance	500 m
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Uniform and non-uniform hotspots
Backhaul	X2
Propagation/channel model	Short-term fading and Lognormal shadowing No fast fading for any of the links
Mobility model	Static users
Traffic model	Full buffer and non-full buffer
Services	Various QoS classes
Number of transmit/receive antennas (for MIMO schemes)	1x1 (downlink)
KPIs, metrics involved	Average throughput per user DL and UL packet throughputs
Description of the problem to be solved (target) and proposed method for solution	Minimizing a cost function of packet delay, interference levels and traffic load
Evaluation method	Analytical and system level simulations (MATLAB)

Links with other work packages: none

[†] A switching point is defined as the point in which a small cell BS switches from UL to DL mode

2.2.2 ON/OFF power saving in campus of small cells

This scenario will evaluate the performance of ON/OFF power saving techniques where a chosen set of small cells (ES small cells) are set OFF while another set of small cells are kept transmitting at maximum power (compensating base stations).

Single and multiple cells compensation based ON/OFF energy saving is currently discussed in 3GPP[6] and two level network planning is considered as a solution for the determination of the compensation small cells set. Primary network planning is considered for the full loaded network and another network planning is considered for lower UE traffic.

We will propose a SON inspired algorithm for finding the compensation base stations in a group (i.e. campus) of base stations coordinated by a central node (called as campus GW) that will provide management and group RRM for the campus (Figure 5).

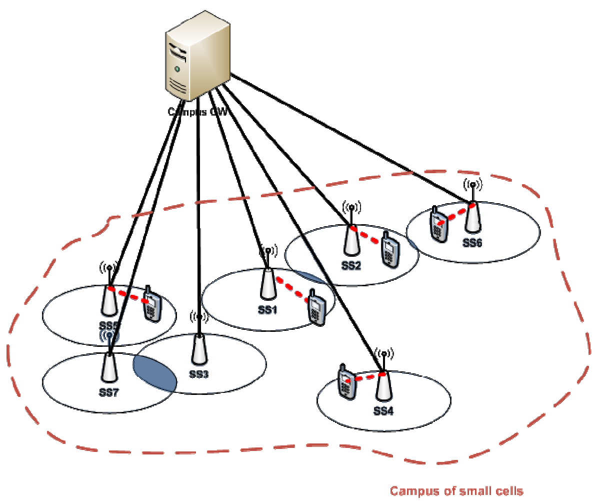


Figure 5: Campus of small cells in ON/OFF power saving scenario

The parameters of the scenario are further described through the following table:

Scenario aspect	Description
Title	ON/OFF power saving in campus of small cells
Task	T4.3
Network topology	Coordinated group of small cells (campus)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A Pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	Random deployment of the campus
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense/highly dense campus
Backhaul	Ideal and non ideal backhaul for the small cells.
Propagation/channel model	Path loss: outdoor pico model of 3GPP TR 36.814[7] Shadowing: Fixed Fast fading: none
Mobility model	Static to low mobility UEs
Traffic model	Spatial Poisson distribution with higher intensity around the pico cells (as in 3GPP[8]).
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Description of the problem to be solved (target)	SON techniques for finding the compensation small cells in the campus of the base stations.
Evaluation method	System level simulations

Links with other work packages:

The scenario is used in T4.3 as baseline for the evaluation of the ON/OFF power saving. Large campuses are used in T4.4 for the evaluation of the distributed synchronization algorithms. The scenario have link with WP6 since it assume new coordination node (campus GW) that coordinate between radio resources management (RRM) actions in the campus additional signaling and/or interfaces are needed for such common RRM.

2.3 Deployment scenario 3: LTE HetNet (LTE macro+LTE micro/pico/femto)

Deployment scenario 3 gathers the following 13 scenarios involving LTE HetNet (LTE macro+LTE micro/pico/femto):

1. Enhanced Inter-Cell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets
2. Antenna tilt optimization for interference management in LTE-A HetNets
3. HetNet energy saving via eNodeB sleep mode/cell switch-off
4. Dynamic cell ON/OFF power saving
5. HetNet mobility
6. LTE-A multi-layer network in urban/suburban environments
7. LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul
8. Opportunistic ON/OFF Switching for small cells
9. Backhaul offloading via Opportunistic caching
10. Power saving through sum power optimization in HetNet deployements
11. Antenna Smart Grid Solutions For Outdoor DAS
12. Joint interference and location prediction
13. Performance and energy efficiency evaluation in LTE Heterogeneous networks

2.3.1 Enhanced Inter-Cell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets

This scenario will evaluate the impact of 1-interference on network performance 2-self-optimization in co-channel deployment of macro and pico layers.

This scenario will study the impact of *eICIC* parameters on the network performance, namely: 1-pico cell *Range Extension* (*biasing*) and 2-*Muting Ratio*. Such a performance evaluation will enable us to study the impact of these parameters, their advantages/drawbacks especially for cell edge performances and will provide an insight into the optimum regions of operation in a given network.

More precisely the scenario will allow us to 1-study the effect of traffic absorption by the pico biasing on cell-edge/cell-center SINR and throughput, 2-study the effect of macro sub-frame blanking, its advantages for pico users in terms of cell edge quality and disadvantages for macro users in terms of call blockings, 3-define joint network KPIs for evaluating network performance in terms of changes in pico biasing and macro Muting Ratios and 4- propose a centralized iterative stochastic process based self-optimization mechanism for optimizing the network performance.

The scenario will consist of a central loaded base station deploying several pico cells to offload traffic (c.f. Figure 6). This will be surrounded by the first tier neighbors. A Monte-Carlo based system level LTE-A simulator for downlink will be used to replicate a real network.

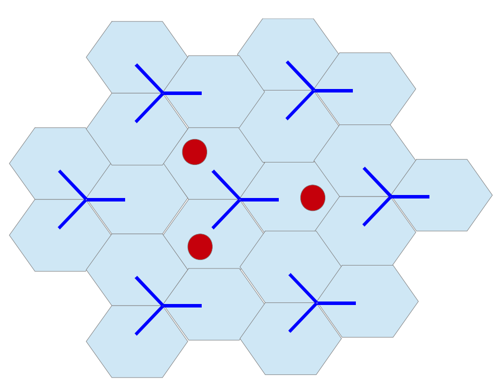


Figure 6: eICIC based interference management for LTE-A HetNets with pico cells

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Enhanced InterCell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A Pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	500 meters for macro-to-macro 250 meters for macro-to-pico 100 meters for pico-to-pico
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense, all of which are deployed only in the congested macro cells
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small and macro cells
	Ideal backhaul for all other interfaces
Propagation/channel model	Macro to UE: 128.1+37.6log10(R[km]) Pico to UE: 140.7+36.7log10(R[km]) (3GPP Model 1, TR 36.814) Lognormal shadowing standard deviation: 6 dB
Mobility model	2/3 of users static and within small cells 1/3 of users mobile at 30 km/h and within macro cells
Traffic model	Regular Poisson distribution based arrivals with higher intensity in Hotspot and regular intensity in all other areas
Services	Data: 100% of users FTP (file size = 16 MB)
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR,
Description of the problem to be solved (target) and proposed method for solution	eICIC optimization for interference management: 1. Minimizing a joint performance metric of cell edge and cell center SINRs under constraints on Macro Block Call Rate. 2. Use of surrogate based iterative self-optimization procedures to achieve the above objectives.
Evaluation method	System level simulations

Links with other work packages: none

2.3.2 Antenna tilt optimization for interference management in LTE-A HetNets

This scenario investigates the impact of Active Antenna System (AAS) based tilt optimization in a heterogeneous network (Figure 7). Although studies have been carried out to investigate the impact of antenna tilt changes for a regular macro network, none have been done so far for a HetNet scenario.

The interference impact of antenna tilts on low-power-nodes/Picos, the relative advantages in terms of total network capacity enhancements due to addition of Pico cells or degradations due to Macro induced interferences have not been addressed so far. Hence this scenario allows us to 1- define and evaluate Macro and Pico centric KPIs and the impact on them due to antenna tilts 2- understand the capacity-coverage tradeoffs due to antenna tilts; 3- develop tilt based self-optimization stochastic approximation methodology to optimize the network based on operator centric objectives which could be based on either or a combination of cell-edge/cell-center SINR/Throughputs.

In order to achieve this goal; AAS based antenna tilts to a central higher traffic cell containing several Pico cells surrounded by a first tier neighbor, will be carried out using a downlink system level simulator and optimization performance evaluated using the defined KPIs.

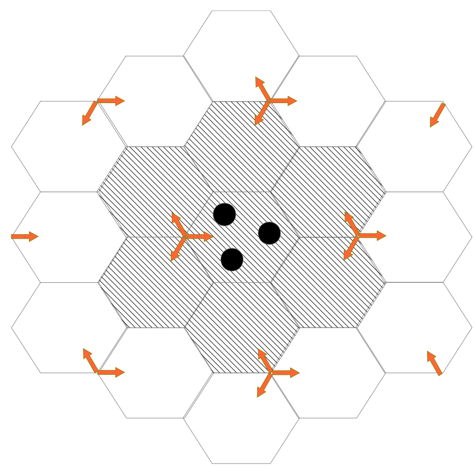


Figure 7: AAS based interference management with pico cells and optimization region

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Antenna tilt optimization for interference management in LTE-A HetNets
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A Pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	500 meters for macro-to-macro 250 meters for macro-to-pico 100 meters for pico-to-pico
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense, all of which are present only in the most congested central macro cell
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small and macro cells
	Ideal backhaul for all other interfaces
Propagation/channel model	Macro to UE: 128.1+37.6log10(R[km]) Pico to UE: 140.7+36.7log10(R[km]) (3GPP Model 1, TR 36.814) Lognormal shadowing standard deviation: 6 dB
Mobility model	2/3 of users static and within small cells 1/3 of users mobile at 30 km/h and within macro cells
Traffic model	Poisson arrivals with constant average arrival rate λ and constant average service time μ.
Services	Data: 100% of users FTP (file size = 16 MB)
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Block Call Rate, Pico and Macro Cell Edge Throughput, Cell Edge SINR, Pico and Macro Cell Center Throughput, Cell Center SINR
Description of the problem to be solved (target) and proposed method for solution	Antenna tilt optimization for interference management: 1. Maximizing sum of cell edge throughput and cell center throughputs under constraints on Block Call Rate. 2. Use of surrogate based iterative self-optimization procedures to achieve the above objectives.
Evaluation method	System level simulations

Links with other work packages: none

2.3.3 HetNet energy saving via eNodeB sleep mode/cell switch-off

This scenario will be used to evaluate the performance of an energy saving scheme, where underutilized low-power cells are switched to sleep mode, or switched off completely, when they are not needed to serve close-by users. The network consists of a macro cell layer and a small cell layer operating on the same carrier frequency. The outdoor small cell layer is assumed to be planned in the sense that the small cells are deployed within the traffic clusters, where they are needed to provide the required area capacity during some part of the day. The main principle is that the network is able to serve the hourly offered traffic with an acceptable cell-edge user performance throughout the day.

The system simulations are assumed to be semi-dynamic, which means that the users are assumed to be static, but the user data traffic and the RRM is assumed to be time-dynamic, and modeled on the TTI (1 ms) level. New users are created in random and 3D network positions following the desired (hourly) distribution between residential, commercial and outdoor users.

Only downlink is modeled in detail. For uplink, a very simple model of the mobile station transmission powers is included, enabling the estimation of the received uplink power levels at the base stations.

A dynamic energy saving algorithm is assumed. If the pico cell utilization is judged to be sufficiently low (based on some criteria, e.g. cell throughput or cell resource utilization), the cell is switched to sleep mode, meaning that all downlink transmissions are discontinued. This also means that the users are not able to access a sleeping pico cell. If (based on some criteria/measurements) a sleeping pico cell would be needed to serve close-by users, the energy saving algorithm will initiate a cell re-activation process, after which the users will be able to access the pico cell.

In addition to the sleep mode, fast cell DTX can be applied to active, but idle cells. In case of fast cell DTX, part of the base station, typically the power amplifier is switched off in between the CRSs. In doing so, the base station power consumption can be reduced, while still keeping the cell accessible for the users.

Furthermore, in addition to the sleep mode, the underutilized pico cells can be switched off completely. While the power consumption will become lower compared to a sleep mode, the cell re-activation can take a longer time, which should be taken into account when designing the cell switch-off algorithm.

In case of base station power consumption models, input from previous projects, such as EARTH, will be utilized as much as possible.

The details of the scenario are summarized in the table below:

Scenario aspect	Description
Title	HetNet energy saving via eNodeB sleep mode/cell switch-off
Task	T4.3
Network topology	HetNet (LTE macro + LTE outdoor pico)
Radio Access Technology (-ies)	LTE(-A)
Nature of small cells	LTE pico
Environment	Urban, a mixture of residential and commercial areas/buildings and areas without buildings (parks, roads etc). An example is shown in Figure 8
Context	Both outdoor and indoor users, only outdoor cells
Inter-site distance	500 m for macro cells
	Irregular for the small cell layer (a planned deployment within traffic hotspots). An example is shown in Figure 9
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Sparse to dense (irregular), see Figure 9
Backhaul	Non-ideal (X2)
Propagation/channel model	WINNER C2 (NLOS) for the macro-cellular propagation. Recursive street-level propagation for the micro-cellular propagation within the traffic cluster and within the street canyons. A more generic micro-cellular propagation for larger NLOS distances between bins, e.g. ITU-R P1411[9] "over-the-rooftop" model. NLOS and LOS building penetration models as described in COST-231[10][11]. 3D propagation for the macro-cellular propagation (floor height gain) Car body loss for in-vehicular users. 3D eNodeB antennas both for macro (down-tilted 3-sector) and pico (omni-directional) Lognormal shadowing with exponential spatial correlation for all links (standard deviation and the correlation distance will vary). No fast fading for any of the links.
Mobility model	Static users. 80% inside the modeled buildings, 20% outdoor or inside vehicles
Traffic model	3GPP FTP model 1[12] with a fixed packet size (e.g. equal to 500 kB). Hourly offered area traffic will vary as a function of time. The fractions of residential, commercial and outdoor traffic will vary as a function of time. An example is shown in Figure 10
Services	100% data (FTP)
Number of transmit/receive antennas (for MIMO schemes)	2x2 (downlink), 1x2 (uplink)
KPIs, metrics involved	Average throughput for the worst 5^{th} percentile of the users (system coverage) Offered area traffic, served area traffic (system capacity) Average cell utilization Average cell sleep probability Average cell switch-off probability Total network power consumption Daily network energy consumption (over 24 hours)
Description of the problem to be solved (target) and proposed method for solution	Minimizing total energy consumed by macro cells and small cells through intelligent sleep mode and/or cell switch ON/OFF schemes
Evaluation method	System level simulations

Links with other work packages: none

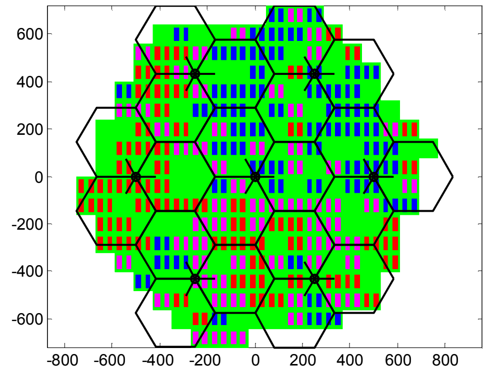


Figure 8: Distribution of the different types of areas and buildings. Commercial buildings are marked as blue, residential as red, and mixed (both commercial and residential floors) as magenta. Outdoor areas are marked as green.

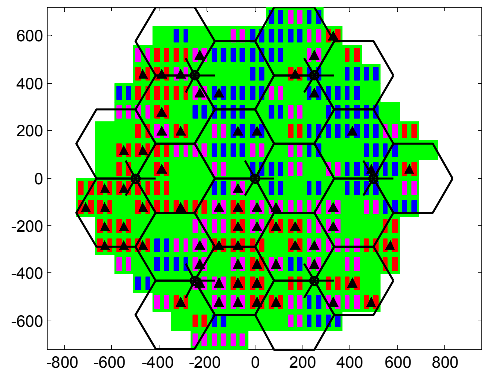


Figure 9: Locations of the outdoor pico sites, as indicated by the black triangles.

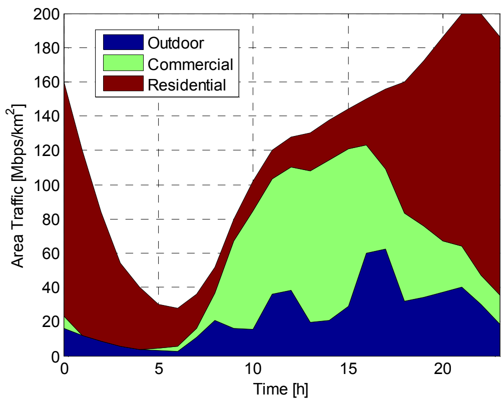


Figure 10: Assumed residential, commercial and outdoor area traffic volume as a function of time.

The KPIs which will be used for this scenario are detailed below:

1. **System coverage** is estimated by looking at the average throughput for the worst 5th percentile of the users. The average throughput is calculated by dividing the size of the transmitted packet with the time it took to transmit the packet.
2. **System capacity** is estimated by looking at the offered area traffic or the served area traffic, measured as Mbps/km^2. Served area traffic is measured as the total number of successfully transmitted bits within all cells in the system divided by the total system area and the simulation time.
3. **Average cell utilization** is defined as the percentage of the time and frequency domain resources used within a cell during the simulation time. A separate utilization value will be calculated for each hour.
4. **Average sleep mode probability** is defined as the percentage of time a pico cell is in sleep mode. A separate value will be calculated for each hour. Similarly, if cell switch-off is applied, average switch-off probability will be calculated.
5. **Total network power consumption** is estimated by looking at the average network power consumption during each hour, i.e. when the average offered area traffic is assumed to be fixed, taking into account both the power consumed during the active and the idle periods of eNodeB operation. Total network power consumption (kW) is calculated as the total power consumed by all the operational macro and pico base stations within the system.
6. **Daily network energy consumption** (kWh) is calculated as the sum of the hourly network energy consumption values over a period of 24 hours.

Note that both the total network power consumption and the daily network energy consumption can be normalized by dividing the power and energy consumption values with the network area (kW/km^2 or kWh/km^2).

The assumed evaluation method is multi-cell system level simulations. The network consists of a macro cell layer and a small cell layer operating on the same carrier frequency. The outdoor small cell layer is assumed to be planned in the sense that the small cells are deployed within the traffic clusters, where they are needed to provide the required area capacity during some part of the day. The main principle is that the network is able to serve the hourly offered traffic with an acceptable cell-edge user performance throughout the day.

The system simulations are assumed to be semi-dynamic, which means that the users are assumed to be static, but the user data traffic and the RRM is assumed to be time-dynamic, and modeled on the TTI (1 ms) level. The traffic model is based on the 3GPP FTP model 1. Hence, a Poisson process is applied to model user arrivals utilizing the assumed hourly offered area traffic value as an input. New users are created in random and 3D network positions following the desired (hourly) distribution between residential, commercial and outdoor users.

After the user traffic has been created, a serving cell is assigned to it. The serving cell selection is assumed to be based on the received downlink signal strength (RSRP), taking the possible cell individual offset values into account, when applicable. Next, the user initiates a packet transmission, and when the packet has been successfully transmitted, the user leaves the system.

Only downlink is modeled in detail. For uplink, a very simple model of the mobile station transmission powers is included, enabling the estimation of the received uplink power levels at the base stations.

Round robin scheduling with prioritized re-transmissions is applied in time-domain, while no multi-user scheduling is assumed in frequency-domain. Ideal link adaptation is assumed.

When calculating the amount of transmitted bits for the scheduled users, the first step is to estimate the SINR per resource block. Next, the SINR is mapped to bits (per resource block) utilizing input from a separate link-to-system model. Each scheduled user is allocated a sufficient number of resource blocks required to empty the current transmission buffer, however not more than 50 resource blocks (10 MHz). Furthermore, a check is made for transmission errors leading to retransmissions in the coming TTIs. Finally, the correctly received bits are moved from the TX buffer to the RX buffer, and the scheduling loop is restarted again for the next TTI.

The energy saving algorithm is operating on the side of the scheduling loop described above. If the cell utilization is judged to be sufficiently low (based on some criteria, e.g. cell throughput or cell resource utilization), the cell is switched to sleep mode, meaning that all downlink transmissions are discontinued. This also means that the users are not able to access a sleeping cell. If (based on some criteria/measurements) a sleeping cell would be needed to serve close-by users, the energy saving algorithm will initiate a cell re-activation process, after which the users will be able to access the cell.

In addition to the sleep mode, fast energy saving mechanisms can be applied to active, but idle cells. For example, in case of micro sleep part of the base station, part of the base station, typically the power amplifier, is switched off in between the CRSs. In doing so, the base station power consumption can be reduced, while still keeping the cell accessible for the users.

Furthermore, in addition to the sleep mode, the underutilized cells can be switched off completely. While the power consumption will become lower compared to a sleep mode, the cell re-activation can take a longer time, which should be taken into account when designing the cell switch-off algorithm.

In case of base station power consumption models, input from previous projects, such as EARTH[13], will be utilized as much as possible.

2.3.4 Dynamic cell ON/OFF power saving

This scenario studies and proposes energy efficiency strategies, applicable during low activity periods, consisting of intelligently switching on/off radio nodes. The main assumption is being in a dense urban scenario where the cell deployment is oriented to cover the peak traffic hour, being unused during certain other periods.

The scenario can consider just macro cells or heterogeneous deployments. The precision of the results obtained will be determined by the availability of reliable power models for each cell involved in this study. In case no power models can be used inside SHARING, the results will be given as % savings.

The algorithm relies on two main inputs:

1. Instantaneous traffic demand and envisaged traffic for the following period. With the former parameter, the system will be able to decide whether a given moment is suitable to apply the energy savings method, in case the amount of traffic served by the network can be handled with fewer cells. The latter one indicates if it is appropriate to launch the algorithm. It tries to anticipate the behavior of the traffic for the next minutes/hours so as to be sure it is not going to increase again above the levels on which the previously switched off cells might have to be re-switched on again.
2. Number of users allocated by the cell and users on neighboring ones. So as to be able to manage all possible interactions, these parameters must be pre-known. There are two possible approaches. A static network model, in which it is assumed that there is a network management center aware of traffic and user allocated in each cell. This management center is in charge of deciding which cells must be ON and OFF at each moment. In case of a dynamic approach, each cell knows not only its own status but also the status of the neighboring cells. If it detects a potential ON/OFF change, the cell itself is able to launch the process and force the new layout.

Figure 11 shows the process of switching off a base station in the scenario where the total amount of resultant traffic can be covered by neighbor cells (right side) and the associated process of switching on some base stations in areas where a peak in traffic is detected.

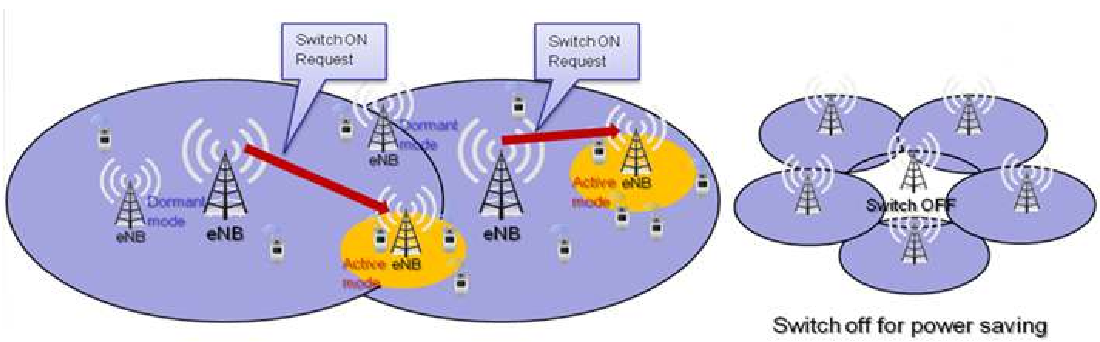


Figure 11: Dynamic cell ON/OFF power saving

The characteristics of the scenario are summarized in the following table:

Scenario aspect	**Description**
Title	Dynamic Cell ON/OFF power saving
Task	T4.3
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE pico/micro/femto (possibility to include WiFi APs[‡])
Environment	Dense urban or urban or suburban
Context	Outdoor
Inter-site distance	Dynamic (ISD is a varying parameter)
Frequency deployment strategy	Co-channel for LTE+LTE, separate frequencies for LTE+WiFi
Frequency bands	LTE licensed bands and Wi-Fi bands
Density of small cells	Dense
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small cells and macro cells
	Ideal backhaul for all other interfaces
Propagation/channel model	NA
Mobility model	Static (mobility modeled as changes in traffic profiles)
Traffic model	Real daily traffic patterns
Services	Voice: %100 of users Data: %100 of users FTP (file size = 8 MB)
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Avg. cell throughput, %savings, µJ/bit (if power models available)
Description of the problem to be solved (target) and proposed method for solution	Optimize the power consumption in urban scenarios where cells may be active but unused during certain periods of the day.
Evaluation method	Analytical

Links with other work packages: none.

[‡] This scenario will primarily deal with LTE HetNets (LTE macro+LTE micro/pico/femto). There is a possibility to include Wi-Fi APs at a second stage. Therefore, this scenario is included in the 3rd deployment scenario which is on LTE HetNets (LTE macro+LTE micro/pico/femto).

2.3.5 HetNet mobility

This scenario is used to evaluate the mobility performance within a heterogeneous LTE deployment. Topics such as handover robustness, dual-connectivity and uplink/downlink split will be considered. The dynamical system simulation setup will in general be based on 3GPP case 1 (3GPP TR 36.814, v9.0.0).

The low power nodes can be located according to hotspot traffic or uniform random distributed locations within given binding conditions. A low power node (LPN) can create a cell by its own or be part of a combined cell scheme, where the LPN would be recognized by the UE as one of several transmission (and/or reception) points of one specific cell. For example, a Macro cell might contain several LPNs that act as distributed remote radio units (RRU) for the main macro unit, and operate with lower power that a macro main unit. Also a LPN could form its own cell with at least one carrier in the same frequency than the macro layer (co-channel deployment).

The system simulations are assumed to be dynamic where user generation, user mobility, traffic model and RRM is assumed to interact dynamically and are modeled at least on the TTI level.

The details of the scenario are summarized in the table below:

Scenario aspect	Description
Title	HetNet mobility
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE pico
Environment	Urban and suburban
Context	Outdoor cells
Inter-site distance	500 meters (urban), 1732 meters (suburban) for macro
Frequency deployment strategy	Same or separate frequency deployments
Frequency bands	LTE licensed bands
Density of small cells	Sparse to dense, depending on number of small cells per macro cell
Backhaul	Non-ideal (X2)
Propagation/channel model	Path loss: As in TR 36.814 (Macro cell model 1, Pico cell model 1) Channel model: TU[14] or ITU with fast fading
Mobility model	Stationary users (to create background load) Mobile users, all moving in random direction at same fixed speed of 3, 30, 60 or 120 km/h
Traffic model	FTP (download and/or upload) Uniform or hotspot distribution
Services	All users have same service Possible addition of stationary background traffic users to increase network load
Number of transmit/receive antennas (for MIMO schemes)	2x2 (downlink), 1x2 (uplink)
KPIs, metrics involved	Average throughput for the worst 5th percentile of the users Offered traffic , served traffic Average throughput considering all the users Handover failure rate
Description of the problem to be solved (target) and proposed method for solution	Maximizing handover robustness Maximizing down- and uplink user throughput
Evaluation method	System level simulations

Links with other work packages: none

2.3.6 LTE-A multi-layer network in urban/suburban environments

This scenario is based on a real environment using High Resolution (HR) map data, realistic BS/UE deployments and deterministic propagation models. All evaluated deployments are LTE co-channel scenarios, i.e. all cells in the network are operating on the same carrier frequency.

The scenario is able to address either dense urban, urban or suburban topologies. The network deployment is created over the 3D description of the real environment: The raster DTM (Digital Terrain Elevation) represents the terrain elevation with a resolution of 5 meters in the horizontal plane and a vertical precision of 1 meter, while 3D vectors represent the buildings, vegetation, bridges and water bodies with 1-meter precision in horizontal and vertical coordinates.

The macro layout is typically organized as one or more rings around a central three-sector site, macro base stations being deployed with an inter-site distance of 500 m in a hexagonal manner, as shown in Figure 12(a). The study area corresponds to the surface theoretically covered by the central macro-cells. Base stations outside this study area are nevertheless included to generate an accurate interference pattern inside the study area. The positions and heights of the sites are adjusted to consider realistic site positions, i.e. they are placed on slightly dominant rooftops, and sector antennas are distributed at the rooftop edges. Each site is composed of three sectors with directive antennas.

The outdoor small-cells (SCo) are deployed either into hotspot areas or uniformly within the whole study area with a quasi-constant Inter-Site Distance (ISD). SCo layout may be designed by an automatic deployment tool that distributes antennas along the streets with an almost-regular user-defined ISD. See the example in Figure 12(a).

Random Indoor Small-cells (SCi) deployments can be generated into building floors within the study area, based on some density user-defined parameters. An example is given in Figure 12(b). Two different SCi access modes may be selected: open or closed. In case of the closed access mode, two different types of users are simulated: subscriber or non-subscriber.

Finally, users are distributed over the simulation area in two different ways:

- Uniformly, respectively indoors and outdoors; an indoor ratio (e.g. 80%) sets the percentage of users located inside buildings.
- Or according to a traffic map that defines local user densities.

The second approach permits the non-uniform user densities (hotspots in particular) to be simulated. Therefore the ability of a given HetNet topology to manage real user traffic distributions may be assessed.

This scenario will be used to evaluate/optimize network topology & configuration to achieve targets expressed in terms of capacity, fairness, and energy at both coverage and system-level. It may also be integrated into third-party tools to confront innovative partner's algorithms with realistic deployments and propagation models.

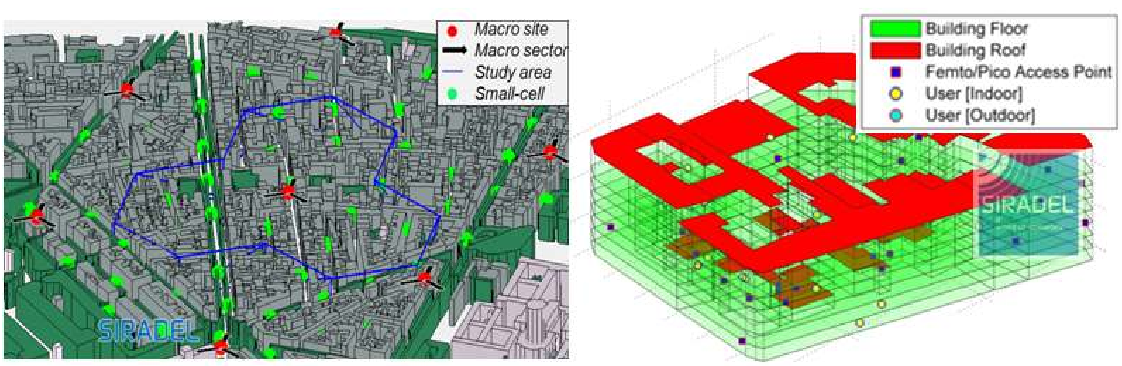


Figure 12: Example deployment scenarios: (a)Macro+outdoor small-cells, (b)Indoor small-cells.

The following table summarizes the characteristics of this scenario:

Scenario aspect	**Description**
Title	LTE-A multi-layer network in urban/suburban environments
Task	T3.1, T3.2, T3.3[§]
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE pico/micro/femto
Environment	Dense urban, urban or suburban
Context	Both outdoor and indoor
Inter-site distance	About 500 meters for macro-to-macro Typically from 50 to 200 meters for small cell-to-small cell
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense
Backhaul	Ideal backhaul
Propagation/channel model	Deterministic path-loss and channel models, based on fast and advanced ray-tracing.
Mobility model	Static users in coverage-based analysis Mobile users in system-level
Traffic model	Heterogeneous and realistic spatial distribution Time-variant User-profile dependent
Services	Voice and data (full buffer model)
Number of transmit/receive antennas (for MIMO schemes)	Multi-antenna systems
KPIs, metrics involved	Service coverage, spectral efficiency, throughput, energy efficiency, …
Description of the problem to be solved (target) and proposed method for solution	Optimizing network topology & configuration to achieve targets expressed in terms of capacity, fairness, energy, etc
Evaluation method	Coverage-based analysis + System-level simulations

Links with other work packages: This advanced simulation environment is used as a basis for scenarios in sections 2.3.7 and 2.4.1 which are in WP4.

[§] This scenario provides a sophisticated and realistic environment for performance evaluation of HetNets. Therefore it is transversal and can be used to evaluate the performance of the proposed innovations in tasks T3.1, T3.2 and T3.3.

2.3.7 LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul

This scenario is based on the same deployment characteristics as described in section 0. System parameters differ from the following two aspects:

- Frequency deployment may consider Carrier Aggregation (a link with the carrier aggregation deployment scenario)
- Non-ideal backhaul, i.e. considering capacity limitations (mainly for user data transmission)

The following table summarizes the characteristics of this scenario:

Scenario aspect	**Description**
Title	LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul
Task	T4.1
Network topology	HetNet: overlay of macro cells and small cells
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE pico/micro/femto
Environment	Dense urban, urban or suburban
Context	Both Outdoor and Indoor
Inter-site distance	About 500 meters for macro-to-macro Typically from 50 to 200 meters for small cell-to-small cell
Frequency deployment strategy	Co-channel deployment with/without Carrier Aggregation[**]
Frequency bands	LTE licensed bands
Density of small cells	Dense
Backhaul	Non-ideal backhaul, i.e. considering capacity limitations (mainly for user data transmission)
Propagation/channel model	Deterministic path-loss and channel models, based on fast and advanced ray-tracing.
Mobility model	Static users in coverage-based analysis Mobile users in system-level simulations
Traffic model	Heterogeneous and realistic spatial distribution Time-variant User-profile dependent
Services	Voice and data (full buffer model)
Number of transmit/receive antennas (for MIMO schemes)	Multi-antenna systems
KPIs, metrics involved	Service coverage, spectral efficiency, throughput, energy efficiency, …
Description of the problem to be solved (target) and proposed method for solution	Optimizing intra-system load balancing strategies to achieve targets expressed in terms of capacity, fairness, energy, etc
Evaluation method	Coverage-based analysis + System-level simulations

Links with other work packages: This advanced simulation environment is related to the one described in the previous subsection which is in WP3.

[**] This scenario will investigate primarily the case without CA, with a possible extension to include CA. Therefore, it is placed in this deployment scenario on LTE HetNets (LTE macro+LTE micro/pico/femto)

2.3.8 Opportunistic ON/OFF Switching for small cells

We consider the problem of turning ON and OFF small cells as a function of the traffic load, interference levels, QoS requirements, and density of small cells. We propose a self-organizing solution in which small cells autonomously optimize their biasing, power levels and ON/OFF operations. We will also look into the coordinated case in which coupled small cells optimize their ON/OFF switching off.

The considered cost function is a function of traffic load, energy efficiency and latency. The baseline is when all small cells are turned on.

The following table summarizes the characteristics of this scenario:

Scenario aspect	**Description**
Title	Opportunistic ON/OFF switching for small cells
Task	T4.3
Network topology	HetNet (LTE macro + LTE outdoor pico/micro)
Radio Access Technology (-ies)	LTE(-A)
Nature of small cells	LTE pico/micro
Environment	Urban
Context	Both outdoor and indoor areas
Inter-site distance	500 m for macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Uniform and non-uniform hotspots
Backhaul	X2
Propagation/channel model	A mixture of many models: 3GPP Path loss model for macro and small cells as specified in TR 25.814[15], TR 36.814[16] + NLOS building penetration (constant for outer wall + distance-dependent indoor loss + additional loss for heavier indoor walls) Lognormal shadowing with exponential spatial correlation for all links (std and correlation distance will vary). No fast fading for any of the links.
Mobility model	Static users
Traffic model	Full buffer and non-full buffer
Services	Various QoS classes
Number of transmit/receive antennas (for MIMO schemes)	1x1 (downlink)
KPIs, metrics involved	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity) Total network power consumption (per hour) kW/km2 Daily energy consumption (accumulated over 24 hours)
Description of the problem to be solved (target) and proposed method for solution	Minimizing total energy consumed by macro cells and small cells through intelligent sleep mode and/or cell switch ON/OFF schemes
Evaluation method	Analytical and system level simulations (MATLAB)

Links with other work packages: none

2.3.9 Backhaul offloading via opportunistic caching

This scenario looks into the problem of backhaul offloading via proactive small cell BSs. It is assumed that the bottleneck lies at the backhaul, whereby users request a number of video files for a library. The classical case posits that all contents lie at the core network and hence the backhaul suffers from congestion when the network gets overloaded. Instead, we leverage caching and storage capabilities at the edge in which small cells pre-cache judicious contents during off-peak backhaul demands. By pushing the contents at the network edge a higher user satisfaction is obtained and the backhaul is offloaded. We will consider both spatial and social caching exploiting both storage and social networking.

Backhaul is currently one of the most important aspects of network design and will continue to gain importance in light of the fact that 70% of all contents will be video by 2017.

The following table summarizes the characteristics of this scenario:

Scenario aspect	**Description**
Title	Backhaul offloading via opportunistic caching
Task	T4.4
Network topology	HetNet (LTE macro + LTE outdoor pico/micro)
Radio Access Technology (-ies)	LTE(-A)
Nature of small cells	LTE pico/micro
Environment	Urban
Context	Both outdoor and indoor areas
Inter-site distance	500 m for macro
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Uniform and non-uniform hotspots
Backhaul	X2
Propagation/channel model	A mixture of many models: 3GPP Path loss model for macro and small cells as specified in TR 25.814[17], TR 36.814[18]. + NLOS building penetration (constant for outer wall + distance-dependent indoor loss + additional loss for heavier indoor walls) Lognormal shadowing with exponential spatial correlation for all links (std and correlation distance will vary). No fast fading for any of the links.
Mobility model	Static users
Traffic model	Non full buffer
Services	Various QoS classes
Number of transmit/receive antennas (for MIMO schemes)	1x1 (downlink)
KPIs, metrics involved	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity) Average backhaul load saving
Description of the problem to be solved (target) and proposed method for solution	Proactive caching as a means of decreasing the load and backhaul offload
Evaluation method	Analytical using simulation based and possibly real traces.

Links with other work packages: none

2.3.10 Power saving through sum power optimization in HetNet deployments

In this scenario we will evaluate the performance of decentralized interior point log barrier type algorithm[19] for heterogeneous deployment of small cells in a shopping mall.

The proposed power optimization minimizes weighted sum of the base station transmit powers with the requirement of minimum QoS for the cell edge UEs. The optimization problem is solved by the means of interior point methods, more precisely by the means of log barrier interior point optimization. In a second step, we propose a decentralized version of the log barrier interior point optimization by the means of consensus averaging[20].

The power saving is considered in downlink scenario, then an extension will be proposed for uplink.

The shopping mall HetNet deployment is shown in the figure below:

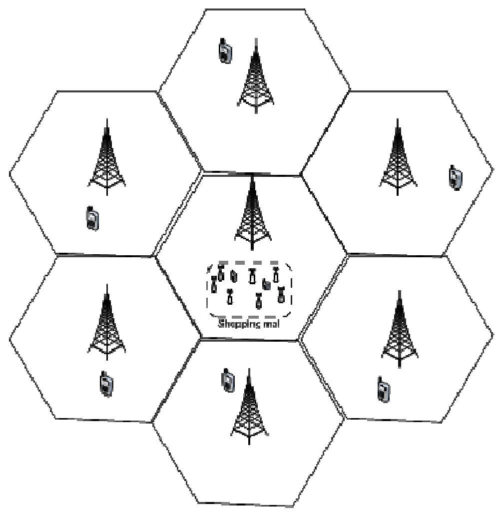


Figure 13: Shopping mall HetNet deployment

The details of the scenario are given in the following table:

Scenario aspect	Description
Title	Power saving through sum power optimization in HetNet deployment
Task	T4.3
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A Pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	500 meters for macro-to-macro Pico cell shopping mall of dimension 400x400 m 19 tri-sector macros with wrap around
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense in the shopping mall and with random deployment
Backhaul	Ideal backhaul between small cells Ideal backhaul between small and macro cells And possibly non-ideal backhaul between small and macro cells
Propagation/channel model	3GPP case 1 for macro and assumptions of 3GPP TR 36.814[21] for small cells
Mobility model	Users static within small cells/macro base stations
Traffic model	Regular Poisson distribution based arrivals with higher intensity in Hotspot and regular intensity in all other areas
KPIs, metrics involved	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Description of the problem to be solved (target) and proposed method for solution	Optimization of the weighted sum of transmit powers based on interior point techniques and their decentralization with cell edge SINR constraint (above -6dB) and cell edge throughput constraints.
Evaluation method	System level simulations

Links with other work packages:

The scenario is used in T4.3 as baseline for the evaluation of the ON/OFF power saving and distributed power saving in more complicated macro interference dependent scenario. The scenario have link with WP6 since it assume new coordination node (campus GW) that coordinate between radio resources management (RRM) actions in the campus additional signaling and/or interfaces are needed for such common RRM.

2.3.11 Antenna Smart Grid Solutions for Outdoor DAS (Distributed Antenna Systems)

In this scenario the aim is to study Outdoor DAS solutions as part of HetNet evolution. Performance is compared to macro cell and small cells solutions, where macro DAS scenarios are studied. Capacity oriented system level simulations are used to evaluate scenarios benefits.

The details of the scenario are given in the following table:

Scenario aspect	**Description**
Title	Antenna Smart Grid Solutions For Outdoor DAS
Task	T.6.2
Network topology	Macro cell/ Small cell and HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A or HSPA[††]
Nature of small cells	LTE pico/micro/femto OR HSPA pico/micro/femto
Environment	Business district
Context	Outdoor
Inter-site distance	To be determined
Frequency deployment strategy	Part of evaluations
Frequency bands	LTE/HSPA licensed bands
Density of small cells	Dense and sparse
Backhaul	NA
Propagation/channel model	Path loss: Okumura-Hata (parameters) Shadowing: lognormal with exponential spatial correlation (parameters) Fast fading: Rayleigh Possibly also Ray Tracing
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Capacity and topology comparison
Description of the problem to be solved (target) and proposed method for solution	Small Cells versus Outdoor DAS Hybrid Solutions Layer Methodologies
Evaluation method	System level simulations

Links with other work packages: none

[††] This scenario will basically study LTE-A, with a possible extension to HSPA. Therefore, it is included in this deployment scenario.

2.3.12 Joint interference and location prediction

At the physical layer, local radio propagation conditions (including interference levels) obviously depend on the relative positions of mobile users and fixed elements of infrastructure. Instead of instantaneous channel state information, some inter-cell interference cancellation and/or coordination (ICIC) schemes rely on averaged-type information such as location and/or average power levels of signal/interference. As an example, ICIC mechanisms may rely on 2D fingerprinting maps (constructed online or offline), based on measurements performed at the mobile terminals, as investigated in the 3GPP LTE mobile femto/macro cellular context.

The objective of the research carried out in this scenario is to exploit radio metrics at the PHY layer that are available at the users via the downlink communications from base stations and via communication between users. These measurements are used to obtain joint location/tracking of mobile terminals and iterative prediction of local propagation conditions and interference. The expected advancements on this topic are two-fold. First we aim at defining semi-deterministic interference models that take into account uncertainty of estimated positions (mobile users and fixed elements) as well as theoretical links between spatial correlation of radio metrics and mobility profile of users (e.g. maximum mobile speed, orientation vector) in order to improve interference prediction. Secondly, we aim at designing adaptive cooperative positioning and tracking algorithms in order to assist subsequent location-based ICIC mechanisms and enable better in-site DSA (Dynamic Spectrum Access), for instance considering cooperative Kalman filter that includes adaptive state models (positioning and speed as state vector and hidden state variable being the propagation model).

The details of the scenario are given in the following table:

Scenario aspect	Description
Title	Joint location and interference prediction for ICIC
Task	T3.3
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A pico
Environment	Dense urban, Urban or rural
Context	Both Outdoor and Indoor
Inter-site distance	500 or 1732 meters for macro-to-macro
	250 meters for macro to pico
	100 meters for pico to pico
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Depends on the configuration
Backhaul	Ideal backhaul for all interfaces
Propagation/channel model	3GPP Path loss model for macro and small cells[22]. Shadowing: lognormal with exponential spatial correlation[23] Fast fading: Typical Urban (TU) model[24]
Mobility model	Depends on the configuration (from 3km/h to 90 km/h)
Traffic model	Full buffer
Services	100% of users sending measurement reports to the eNB.
Number of transmit/receive antennas (for MIMO schemes)	To be defined (from 1x1 to 4x2)
KPIs, metrics involved	- Cdf of the positioning error over the area of interest - Prediction accuracy of interference level versus confidence in a particular location
Description of the problem to be solved (target) and proposed method for solution	Determine interference condition with respect to relative positioning of mobile nodes through semi deterministic definition of interference model taking into account positioning uncertainty.
Evaluation method	- Semi analytical - System level simulations

Links with other work packages: none

2.3.13 Performance and energy efficiency evaluation in LTE Heterogeneous Networks

Energy efficiency is becoming an important metric to assess the performance of advanced communication networks, along with capacity and network QoS. This scenario aims to jointly evaluate energy consumption and user throughput using system level simulations and under realistic traffic models and realistic load evolution. Guidelines for optimizing the energy efficiency in heterogeneous networks (for deployments including macro cells and small cells) are expected as an outcome of this study. Investigations will consider whether increasing the number at the macro cells can reduce the number of small cells required to cope with the load evolution.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Performance and energy efficiency evaluation in LTE Heterogeneous Networks
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	macro-to-macro: 500m
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands 2GHz
Density of small cells	Sparse (2 to 4 per macro cell)
Backhaul	Non-ideal backhaul for all interfaces
Propagation/channel model	3D indoor channel model
Mobility model	3 km/hr
Traffic model	FTP model 1 as defined in TR 36.814
Services	Data (file size = 8 MB)
Number of transmit/receive antennas (for MIMO schemes)	2x2
KPIs, metrics involved	Average cell throughput and cell-edge (5% percentile)
Description of the problem to be solved (target) and proposed method for solution	Maximizing capacity of a hetnet while minimizing power consumption
Evaluation method	System level simulations

Links with other work packages: none

2.4 Deployment scenario 4: Inter-RAT HetNet (LTE + WiFi)

Deployment scenario 4 gathers the following 4 scenarios involving Inter-RAT HetNet (LTE + Wi-Fi):

1. Multi-RAT Heterogeneous networks in urban/suburban environments
2. LTE-WiFi Offloading
3. Seamless Offloading in Heterogeneous Wireless Networks
4. Positioning in Heterogeneous Converged networks

2.4.1 Multi-RAT Heterogeneous networks in urban/suburban environments

This scenario is based on the same deployment characteristics as described in section 2.3.6. System parameters differ from the following two aspects:

- LTE-A cells + WiFi APs
- Wi-Fi unlicensed bands

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Multi-RAT Heterogeneous networks in urban/suburban environments
Task	T4.2, T4.3, T4.4[‡‡]
Network topology	HetNet: overlay of macro cells and small cells
Radio Access Technology (-ies)	LTE-A and WLAN
Nature of small cells	LTE pico/micro/femto and Wi-Fi APs
Environment	Dense urban, Urban or Suburban
Context	Both Outdoor and Indoor
Inter-site distance	About 500 meters for macro-to-macro Typically from 50 to 200 meters for small cell-to-small cell
Frequency deployment strategy	LTE bands and WiFi bands
Frequency bands	LTE licensed bands and Wi-Fi unlicensed bands
Density of small cells	Dense
Backhaul	Ideal backhaul
Propagation/channel model	Deterministic path-loss and channel models, based on fast and advanced ray-tracing.
Mobility model	Static users in coverage-based analysis Mobile users in system-level
Traffic model	Heterogeneous and realistic spatial distribution Time-variant User-profile dependent
Services	Voice and data (full buffer)
Number of transmit/receive antennas (for MIMO schemes)	Multi-antenna systems
KPIs, metrics involved	Service coverage, spectral efficiency, throughput, energy efficiency, …
Description of the problem to be solved (target) and proposed method for solution	Optimizing inter-system load balancing strategies to achieve targets expressed in terms of capacity, fairness, energy, etc
Evaluation method	Coverage-based analysis + System-level simulations

Links with other work packages: This advanced simulation environment has common deployment characteristics with the one described in the subsection 2.3.6 which is in WP3.

[‡‡] This scenario provides a sophisticated and realistic environment for performance evaluation of multi-RAT HetNets (LTE+Wi-Fi). Therefore it is transversal and can be used to evaluate the performance of the proposed innovations in tasks T4.1, T4.2 and T4.3.

2.4.2 LTE-WiFi Offloading

This scenario looks into the problem of dual mode small cells transmitting simultaneously on LTE and WiFi bands. The problem boils down to designing self-organizing load balancing solutions that optimally balances the load among both RATs. The proposed approach is based on reinforcement learning techniques adapted to the specifics of the problem. In addition, the objective function is the aggregate spectral efficiency and cell edge performance.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	LTE-WiFi offloading
Task	T4.2
Network topology	HetNet (macro + outdoor pico)
Radio Access Technology (-ies)	LTE(-A) and WiFi
Nature of small cells	LTE pico/micro/WiFi
Environment	Urban
Context	Both outdoor and indoor areas
Inter-site distance	500 m for macro
Frequency deployment strategy	LTE licensed and WiFi unlicensed bands
Frequency bands	LTE licensed and WiFi unlicensed bands
Density of small cells	Uniform and non-uniform hotspots
Backhaul	X2
Propagation/channel model	A mixture of many models: 3GPP Path loss model for macro and small cells as specified in TR 25.814[25], TR 36.814[26] Lognormal shadowing with exponential spatial correlation for all links (std and correlation distance will vary). No fast fading for any of the links.
Mobility model	Static users
Traffic model	Full buffer and non-full buffer
Services	Various QoS classes
Number of transmit/receive antennas (for MIMO schemes)	1x1 (downlink)
KPIs, metrics involved	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity)
Description of the problem to be solved (target) and proposed method for solution	How to efficiently integrate small cells and WiFi? How to leverage WiFi to improve LTE transmissions
Evaluation method	System level simulations

Links with other work packages: none

2.4.3 Seamless Offloading in Heterogeneous Wireless Networks

This scenario presents a seamless offload scheme between 3GPP and WLAN[§§] networks for real-time packet traffic. This solution would carry heterogeneous mobile broadband networks' fundamental identifiers such as application targets, user's mobility and usage characteristics, network capacity and density, network management, terminal's power state, network congestion status, physical channel parameters to a mathematical plane.

With this model, by taking into account the base protocol functions such as access, error and congestion control, network and channel capacity, data transmission latency and reliability parameters will be improved based on the upper and lower limits of them.

The scenario will allow us to contribute to the following points: 1- User preference as a QoE metric during handover decision will be integrated into the developed MADM (multiple attribute decision making) algorithm. 2-Handover execution will be handled not only based on link-quality including QoS values but also based on subjective measures. 3- Network traffic of the Heterogeneous Wireless Networks (HWNs) will be improved and managed based on user experience.

The scenario is depicted in Figure 14, and consists of UTRAN/GERAN access networks along with a WiFi access point in tight-coupling heterogeneous network architecture.

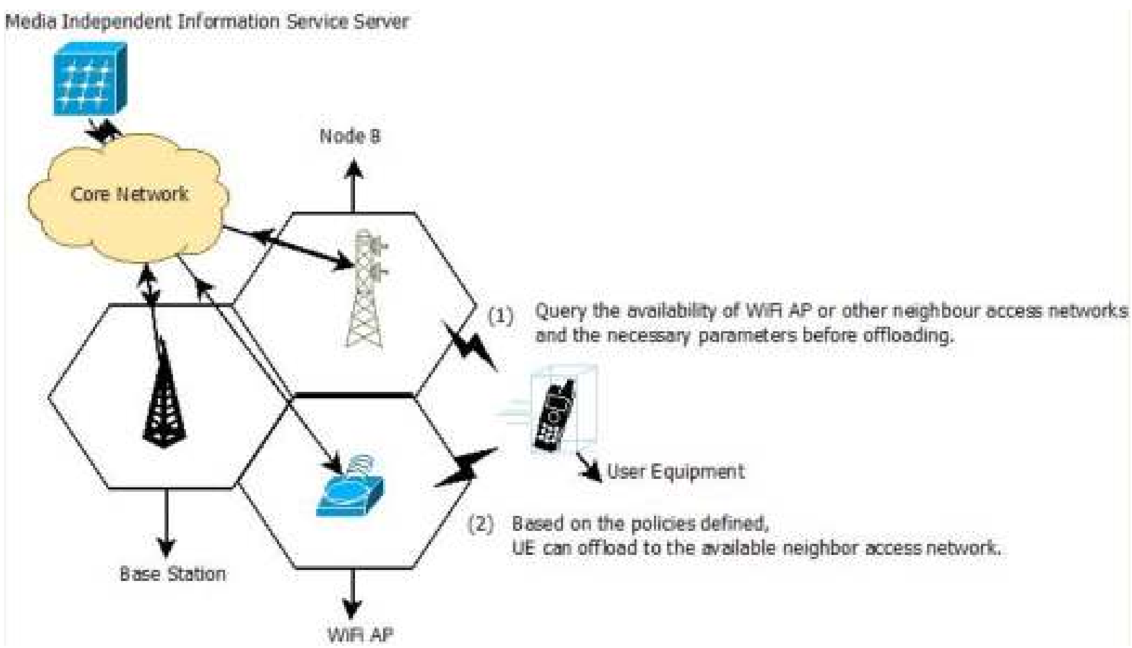


Figure 14: IEEE 802.21 and user experience based offload scenario

[§§] In the deliverable, the terms WLAN, WiFi and Wi-Fi are used in a synonymous manner.

The details of the scenario are summarized in the table below:

Scenario aspect	Description
Title	Data Offloading in Heterogeneous Wireless Networks
Task	T4.2
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	HSPA (or UMTS) and WLAN***
Nature of small cells	Wi-Fi APs
Environment	Urban
Context	Indoor
Inter-site distance	500 meters for macro-to-macro
	20 meters for small cell-to-small cell
	100 meters for macro-to-small cell
Frequency deployment strategy	Separate frequency deployment
Frequency bands	HSPA licensed bands and Wi-Fi unlicensed bands (2.4G)
Density of small cells	Dense
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small cells and macro cells
	Ideal backhaul for all other interfaces
Propagation/channel model	Path Loss models: 802.11: Two-ray Ground Reflection 3G: Path loss UE between BS: L(d) = L_init + 10 * n * log10(d) [27] Here d is the distance between the Node B and the UE in km, L_init is the distance loss at 1 km distance and n is the decay index. L_init and n depends on the environment.
Mobility model	The percentage of cell-edge users is 10%. Random Waypoint mobility models is used
Traffic model	Background traffic : Poisson arrivals
Services	The availability of flat-rate voice and data bundles, and higher demand for entertainment services like YouTube, Apple's iTunes and services such as video streaming from Television Networks.
Number of transmit/receive antennas (for MIMO schemes)	1x1
KPIs, metrics involved	Client SNR (dB) PSNR (dB) Data received (Kbps): Packet Loss (%): Throughput (Kbps): MOS Value (Mean Opinion Score)
Description of the problem to be solved (target) and proposed method for solution	The main purpose of this scenario is to find out a smart way to switch between 3GPP data networks and WiFi networks. For this report, we will be evaluating a client based offloading implementation and a QoE (Quality of Experience)-based innovative data offloading strategy
Evaluation method	Analytical and System level simulations

Links with other work packages: none

*** Although this scenario involves HSPA, it is included in this deployment scenario (but not in the HSPA deployment scenario) since its main focus is offloading cellular traffic to Wi-Fi.

2.4.4 Positioning in Heterogeneous Converged Networks

This scenario is used to study the benefits and the performance of hybrid localization architecture in heterogeneous converged networks. The localization architecture is based on extending E-UTRAN *Minimization of Drive Tests* functionality to incorporate the RF fingerprints of LTE and WiFi small cells.

The scenario consist of a set of overlaying macro base stations (black arrows) and randomly distributed LTE or WiFi small cells (red circles) operating on different frequency band as depicted in Figure 15. The users are uniformly distributed and they move between the cells with constant velocity doing periodic MDT measurement. By processing the MDT measurement reports, operator can construct a database and estimate the location of UEs or the location of randomly deployed small cells. The studied performance indicators consist of positioning error (PE) and confidence of the location.

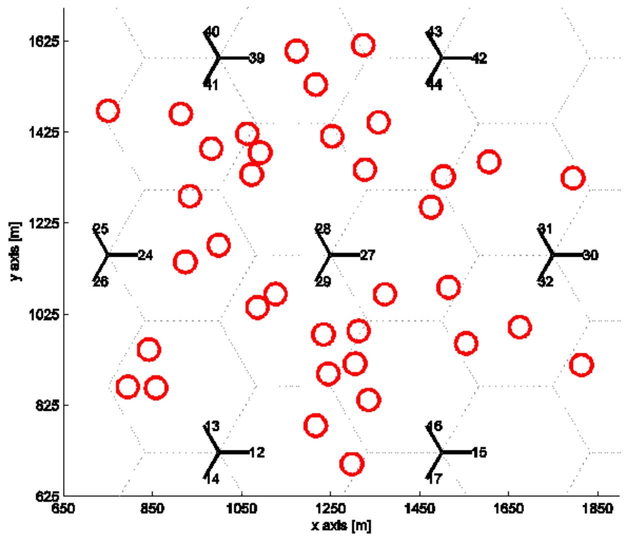


Figure 15: Simulation scenario of converged heterogeneous small cell network

Analyzing the performance of positioning accuracy in this scenario allows us to draw conclusions of the expected performance of various location assisted RRM algorithms such as network based proximity indication which is used for example to trigger UE measurements preceding offloading to small cells. The accuracy of the proximity indication affects for example the amount of unnecessary network monitoring and missed offloading opportunities. Hence, impacting on the UE energy efficiency, small cell utilization and offloading gains. The research is carried out by using a dynamic system level simulator modeling accurately downlink transmissions and particularly the received signal power and quality at UE‘s antenna connector.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Positioning in HetNet (LTE only and LTE+WiFi)
Task	T6.2
Network topology	Inter-frequency HetNet (overlay of macro cells and small cells operating on different carriers)
Radio Access Technology (-ies)	LTE only or LTE + WLAN
Nature of small cells	LTE femto OR Wi-Fi
Environment	Dense urban, Urban or Rural
Context	Outdoor OR Outdoor + Indoor
Inter-site distance	From 500 to 1750 meters for macro-to-macro
	Random, minimum 50 meters for small cell-to-small cell
	Random, minimum 75 meters for macro-to-small cell
Frequency deployment strategy	Separate frequency deployment for macro and small cells.
Frequency bands	LTE licensed band AND Wi-Fi unlicensed bands (2.4G)
Density of small cells	3 small cells per macro cell (sparse).
Backhaul	Ideal backhaul between small cells.
	Idea backhaul between small cells and macro cells.
	Idea backhaul for all other interfaces.
Propagation/channel model	3GPP Path loss model for macro and small cells as specified in TR 25.814[28], TR 36.814[29]. Shadowing: lognormal with exponential spatial correlation as specified in TS 36.839[30]. Fast fading: Typical Urban (TU) model as specified in TS 36.839[31].
Mobility model	100% of users at 3 km/hr or 30 km/h
Traffic model	100% Background loading
Services	100% of users sending measurement reports to the eNB.
Number of transmit/receive antennas (for MIMO schemes)	Receiver: 1x2 MRC
KPIs, metrics involved	Primary KPIs - Cumulative distributions of positioning error over the area of interest. - 68%-ile and 95%-ile prediction accuracies over the area of interest. - Prediction accuracy vs. confidence in a particular location
Description of the problem to be solved (target) and proposed method for solution	Development of hybrid localization architecture relying on 3GPP specifications for network based position estimation of UEs and uncoordinatedly deployed small cells e.g., WiFi access points with unknown location. The proposed solution is based on Radio Frequency (RF) fingerprint localization of enhanced MDT architecture using radio measurements obtained from 3GPP and Wi-Fi networks. The goal is to study: - How accurately location of an unknown UE or small cell can be acquired by means of RF fingerprinting; - Can the estimated location be used to trigger the measurements on the small cell layer when UE is in the proximity of the small cell
Evaluation method	System level simulations and performance measurements in LTE/WLAN environment.

Links with other work packages: This scenario is related to the one in section 2.3.12 (WP3) which also deals with location prediction.

2.5 Deployment scenario 5: Relays

Deployment scenario 5 gathers the following 4 scenarios involving relays:

1. LTE-Advanced collaborative relaying
2. Clustered wireless mesh networks based on LTE
3. Joint channel and Network coding for advanced networks
4. Path loss model for relay

2.5.1 LTE-Advanced collaborative relaying

We consider two collaborative relaying scenarios as depicted in Figure 16 and**Erreur ! Source du renvoi introuvable.**. The first corresponds to the case where two RN can collaborate behind the same eNB to cover UEs which are shadowed from the DeNB (Donor eNB). The key techniques to exploit here are the use of distributed spatial-multiplexing and collaborative-scheduling at the RNs (Relay Nodes). Adaptations to coded-modulation and HARQ protocols to allow for the two techniques to be achieved will be proposed primarily for TDD-based relays. Both decode-and-forward as well as more sophisticated quantize-map-and-forward techniques will be considered. Two-way coding strategies may also be studied. The second scenario is a so-called relay-aided broadcast channel and aims to use a RN in scenarios where multiple UEs are covered by both the DeNB and the RN. Here the RN provides additional spatial-streams in a causal fashion and aims to increase the level of spatial-multiplexing offered by the DeNB. Again, adaptations to coded-modulation and HARQ protocols to allow for such improvements will be proposed.

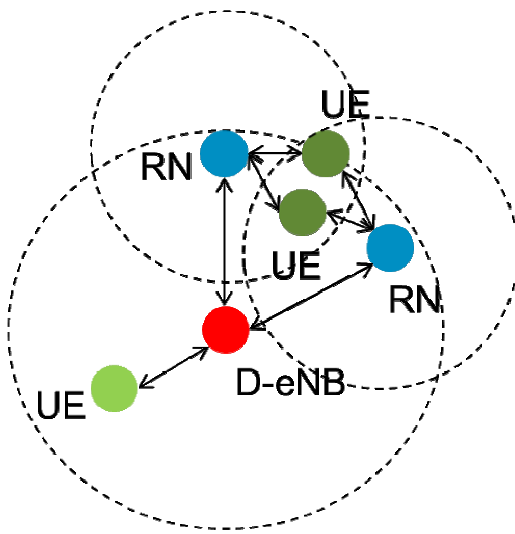


Figure 16: Multi-Relay Collaboration Scenario

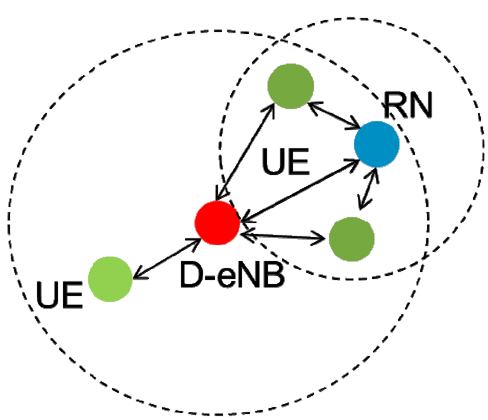


Figure 17: Relay-aided Broadcast

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	LTE-Advanced collaborative relaying
Task	T5.1
Network topology	Cellular network comprised of: • Donor eNB (main eNB of cell) =>scheduling for UE and RN, common control channels, radio resource control master, first gateway to Core Network • Relay nodes (RN) =>scheduling, common control channels, radio resource control slave to D-eNB, master for UE • User equipment (UE), end nodes => can connect to either RN or D-eNB, should be the same for UE, slaves to RN or D-eNB
Radio Access Technology (-ies)	LTE, LTE-A
Nature of small cells	Relay nodes
Environment	Urban and sub-urban coverage extension
Context	Outdoor and Outdoor-to-Indoor
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment
Frequency bands	(LTE) licensed bands
Density of small cells	Dense enough to enable collaboration
Backhaul	Backhaul to core network only available at the donor eNB
Propagation/channel model	Path loss: Okumura-Hata Shadowing: lognormal with exponential spatial correlation (parameters) Fast fading: Rayleigh & Rice
Mobility model	Semi-static (fixed once deployed)
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	Up to 2 antennas per donor eNB and relay node
KPIs, metrics involved	Achievable throughput on relayed eNB-UE link, end-to-end throughput (core network to user)
Description of the problem to be solved (target) and proposed method for solution	How to improve the throughput on the relayed eNB-UE link using cooperation between two or more relays using • Space-time coding • AMC and HARQ protocols
Evaluation method	Link level simulations, System level simulations, Experiments with OpenAirInterface

Links with other work packages: none

2.5.2 Clustered wireless mesh networks based on LTE

The aim of this scenario is to study the performance of wireless mesh network (or network extensions) based on LTE. 3GPP is working actively on Private Mobile Radio (PMR) systems, in order to provide LTE solutions to this market. However PMR systems have very often completely different requirements and use cases, with respect to traditional cellular communications. Much more emphasis is given, for instance, to security, reliability and robustness of the communication, rather than throughput.

The scenario focuses on rapidly deployable wireless mesh networks, to be used to cover an area which is not covered by fixed PMR infrastructure. It could be the case after a major natural disaster. Another possible use case is to deploy a wireless network in areas without any infrastructure, or where the main governmental or market actors do not want to invest on a wired infrastructure. A third use case, similar to coverage extension with relays, is when there is a specific and limited area which is not covered by the fixed network, then a wireless extension can be imagined with possibly multiple relays. Here we will focus on the first use case.

In order to reuse as much as possible the LTE structure and protocols, we propose a clustered wireless mesh network meaning that the network is divided in clusters, mapping (or equivalent) to LTE macro (or micro, depending on the available transmit power, type of equipment, etc.) cells. Each cell is controlled by a ClusterHead (CH) which is acting as a 3GPP eNodeB. Mesh Routers (MR) are acting as 3GPP relays, and inherit relay and UE procedures from LTE. Some MRs, connected to 2 or 3 clusters, are called bridging MRs and allows communications between the clusters. Common bridging MRs between the clusters can cooperate for improving performance (robustness, throughput, latency). Edge MRs are possibly present, if the wireless mesh network is not independent but it is linked to other networks via other technologies. A schematic representation of the clustered mesh network is given in the figure below.

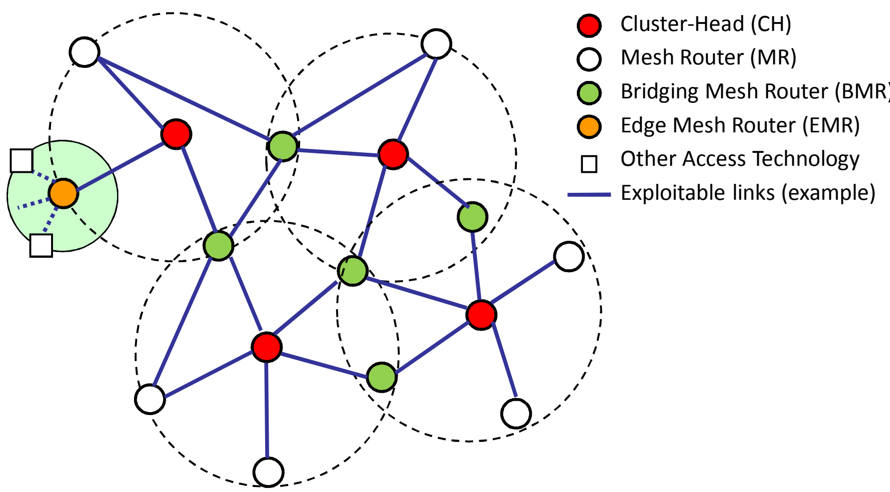


Figure 18: Clusterized wireless mesh network

In this scenario, one critical aspect is inter-cluster communications. To the best of our knowledge, 3GPP LTE Rel 10 does not authorize a Relay Node (RN) to attach to more than one Donor eNodeB, even though many Donor eNodeB may be available during the initialization phase. This scenario will help testing, at PHY layer, cooperative relaying strategies that enable efficient and robust inter-cluster communications. Another challenging aspect of this scenario is the design of adequate radio resource strategies and their corresponding signaling mechanisms that are able to efficiently exploit the benefit brought by the use of cooperative relaying techniques in this networking setting.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Clustered wireless mesh networks based on LTE
Task	T5.1
Network topology	Mesh network comprised of: • Clusterheads (CH) – act as 3GPP eNodeB => scheduling, common control channels, radio resource control master • Mesh routers (MR) – act as 3GPP relay nodes • Bridging–MR (Relays) which are connected to 2 or 3 CH and forward traffic between clusters => collaborative forwarding and distributed signal processing are possible
Radio Access Technology (-ies)	LTE-A
Nature of small cells	NA, here relays (fixed/nomadic) are used for communications between clusters (i.e. cells)
Environment	Urban, Suburban, Rural
Context	Outdoor
Inter-site distance	Few kilometers, for macro-to-macro
	NA for small cell-to-small cell
	NA for macro-to-small cell
Frequency deployment strategy	Co-channel deployment (Inband) or Separate frequency deployment (out of band or frequency division of a common band)
Frequency bands	LTE licensed bands (in particular 700 MHz band, i.e. B14 which is used also for PMR in the USA) Possibly 400 MHz band used for PMR is Europe
Density of small cells	NA
Backhaul	NA
Propagation/channel model	Path loss: Okumura-Hata or some other model adapted to the 700 MHz and 400 MHz band, possibly abstracted in CQI Shadowing: lognormal with iid variables, or absent Fast fading: Rayleigh, 3GPP channel models
Mobility model	100% users at the same speed, from pedestrian to vehicular values
Traffic model	Generic traffic : with Poisson process for simulations Full buffer constant traffic for PHY simulations
Services	Voice: 100% of users Data: TBD% of users FTP, TBD% of users video streaming
Number of transmit/receive antennas (for MIMO schemes)	eNodeB (CH) and MR: maximum 2x2 UE: maximum 1x2
KPIs, metrics involved	For simulation: • Packet Error Rate • Avg. cell/user throughput • Avg. user delay • Avg. fairness index • Min throughput • Max delay • Max drop rate For demonstration[†††] • Achievable throughput/delay/BLER on relayed CH-CH link • end-to-end throughput/delay/BLER (core network to user)

[†††] This scenario is a common one between TCS and EUR. The theoretical studies will be done in WP5 (TCS) and a prototyping/demonstration is foreseen in WP7 (EUR).

Description of the problem to be solved (target) and proposed method for solution	Maximizing sum rate, minimizing delay and maximizing fairness among users in mesh deployment. Study cooperative relaying strategies for inter-cluster communications in a wireless mesh network, with focus on robustness rather than throughput, for PMR services.
Evaluation method	Link level simulations MAC level simulations Experiments with OpenAirInterface[‡‡‡]

Links with other work packages: This scenario is a common one between TCS and EUR. The theoretical studies will be done in WP5 (TCS) and a prototyping/demonstration is foreseen in WP7 (EUR).

[‡‡‡] This scenario is a common one between TCS and EUR. The theoretical studies will be done in WP5 (TCS) and a prototyping/demonstration is foreseen in WP7 (EUR).

2.5.3 Joint channel and network coding for advanced networks

The Multi-Access Relay-channel (MARC) model presented in Figure 19 shows two (or more) User Equipment (UEs) using a relay node (RN), to communicate with a small cell (SC).

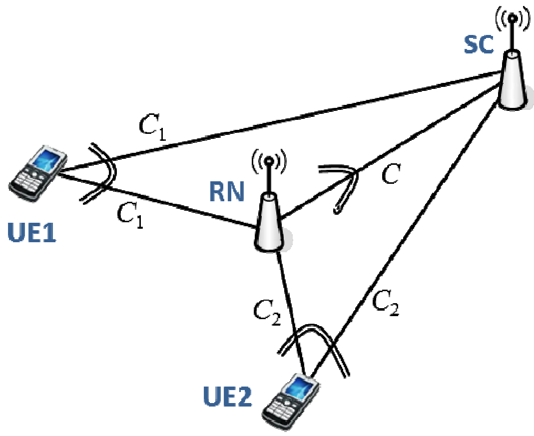


Figure 19: Multi-access relay-channel model

The amount of data transmitted by the relay is usually equal to the amount of data initially transmitted by the sources. Thus, in order to reduce the overload of the relay backhaul link, network coding (NC) can be advantageously used at the relays: instead of separately relaying data packets for each of the users accessing the channel, the NC technique allows combining them together for transmission. Network coding has many advantages such as maximizing throughput and minimizing energy per bit.

In our work we will consider the case of using multiple relays in order both to alleviate the data load at the intermediate nodes and to have a larger coverage extension average. But, though NC for the MARC model has received much attention, studies about NC on multi-user multi-relay wireless networks are still scarce due to its complexity. In particular, we will consider the scheme with 2 sources, 2 relays and 1 destination as depicted in Figure 20. It illustrates the case when 2 UEs use two relay nodes (RN_1 and RN_2) to communicate with a final destination: in this case it only concerns uplink transmissions. UEs' transmissions are encoded by two channel codes $\mathscr{C}_1$ and $\mathscr{C}_2$ respectively, while a network code $\mathscr{C}_{Ri}$ is used at the relay i=1, 2. The destination decodes the received signals using knowledge of $\mathscr{C}_1$, $\mathscr{C}_2$, $\mathscr{C}_{R1}$ and $\mathscr{C}_{R2}$. Consequently, a joint-design of network ($\mathscr{C}_{R1}$, $\mathscr{C}_{R2}$) and channel ($\mathscr{C}_1$, $\mathscr{C}_2$) codes is desired in order to fully exploit these two coding techniques.

Our approach is based on using binary Low-Density Parity-Check (LDPC) codes as channel codes and non-binary (NB) network coding, which offers a natural generalization of binary network coding and allows further optimization of the design.

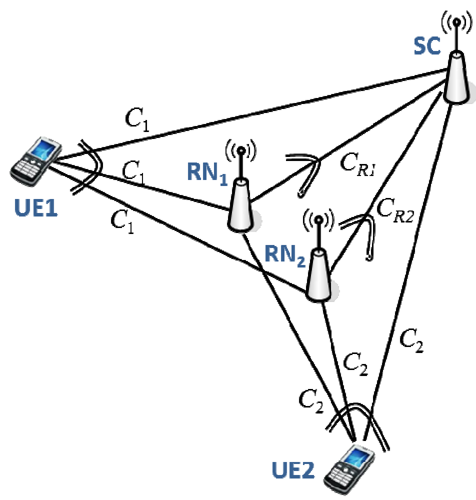


Figure 20: Two-users and two-relays communication system

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Joint channel and Network coding for advanced networks
Task	T5.1
Network topology	Two users connecting to a base station directly and via two relays
Radio Access Technology (-ies)	LTE –like with LDPC codes
Nature of small cells	NA
Environment	Urban or Suburban or rural
Context	Outdoor
Frequency deployment strategy	NA
Frequency bands	NA
Density of small cells	NA
Backhaul	Non-ideal backhaul between relay and Donor eNB
Propagation/channel model	AWGN, block fading
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	1
KPIs, metrics involved	Bit Error Rate
Description of the problem to be solved (target) and proposed method for solution	Analysis and design of Low-Density Parity-Check (LDPC) codes for Joint Network-Channel Coding (JNCC) over the Multiple Access Relay Channel model with two users.
Evaluation method	Link level simulations

Links with other work packages: none

2.5.4 Path loss model for relay scenario

This scenario considers a network densification with relays to increase the average or cell edge user throughput. The benefits of the relay solutions are generally evaluated by system level simulations which define many simulation parameters such as path loss models. From a propagation point a view, the multiple links between a relay, a mobile and a base station can be modeled by two propagation channel models (Figure 21). The first one is the model for a macrocell environment that applies for the macro link between a base station and a mobile or for the backhaul link between a base station and a relay. The difference between a relay or a mobile is given by the antenna height. The second one is the model for a microcell environment that applies for the access link between a relay and a mobile. Path loss models may significantly change simulation results. That’s why path loss models need to be realistic and well-balanced. Models that underestimate the path loss for the macro link and overestimate the path loss for the access link will not promote relay-based solution or microcell densification.

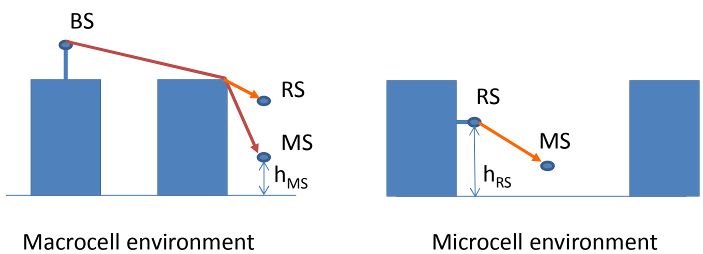


Figure 21: Propagation channel environments for relay scenario

As a first step, a measurement campaign will be performed in an outdoor urban environment. Path loss models for the macro, backhaul and access links will be calibrated with the collected data. The results will be compared with well-known propagation channel models such as COST231-HATA, Winner, 3GPP or ITU channel models. The data analysis will focus on the impact of the relay position (X-Y location and antenna height) on the path loss models.

Next, the ability of the propagation channel to relay the signal will be analyzed. Previous system-level simulations consider traffic assumptions and/or take into account interferences to analyse the throughput but they do not analyze accurately the impact of the propagation channel. A single user scenario will be defined and the theoretical throughput with and without a relay will be calculated using the Shannon capacity equation. The potential gain provided by the relay will only depend on the path loss ratio between the base station, relay and mobile. Different path loss models or measurement data will be used for this study.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Propagation channel path loss
Task	T5.1
Network topology	Relay network
Radio Access Technology (-ies)	Agnostic[§§§]
Nature of small cells	Microcell and macrocell with relay
Environment	Urban
Context	Outdoor
Inter-site distance	Distance BS-MS max: 1000 m
Frequency bands	2 GHz
Propagation/channel model	Path loss for macrocell and microcell environment will be defined from measurement data
Number of transmit/receive antennas (for MIMO schemes)	SISO
KPIs, metrics involved	Path loss and theoretical throughput
Description of the problem to be solved (target) and proposed method for solution	1. Path loss and shadowing characterization for the backhaul and access links 2. Measurement based throughput estimation with relay
Evaluation method	Measurement campaign and Shannon capacity

Links with other work packages: Recommendations for propagation channel models will be provided to assist WP3, WP4 and WP5 participants in using realistic and consistent multi-link path loss models in urban outdoor environment.

[§§§] Although the RAT for this scenario is transparent, the 2 GHz frequency band hints at IMT technologies (GSM900, GSM1800, UMTS, HSPA, LTE/LTE-A).

2.6 Deployment scenario 6: Device-to-Device (D2D)

Deployment scenario 6 gathers the following 3 scenarios involving Device-to-Device communications:

- D2D Unicast communications
- D2D broadcast communications
- D2D communications for overloaded networks

The standardization work on D2D technologies in 3GPP is focused on a set of scenarios, which were identified to fit the needs of both public safety and commercial mobile networks. D2D technologies make use of the direct LTE radio interface between the devices instead of going through the network infrastructure. The main scenarios supported by D2D technologies are:

- Direct 1:1 (one-to-one) communications, also named as D2D unicast communications
- Direct 1:many (one-to-many) communications, also named as D2D broadcast communications

As shown in the table below, the direct 1:1 communication scenario is designed to support the usual data communication service between two users. The direct one-to-many communication scenario is designed in order to support a new groupcast service called as "Group Communication". One UE broadcasts messages to other UEs that can be in proximity within the same cell (area controlled by a single eNodeB) or in different cells (areas possibly controlled by multiple eNodeBs).

Situations	D2D Unicast Communication	D2D broadcast Communication
In Cell coverage	x	x
Out of cell coverage	x	x
Coverage extension with UE relay	x	x

These scenarios should be under the control of the network operator and can happen in various situations, either through the cell coverage (Figure 22) or out of cell coverage (Figure 23).

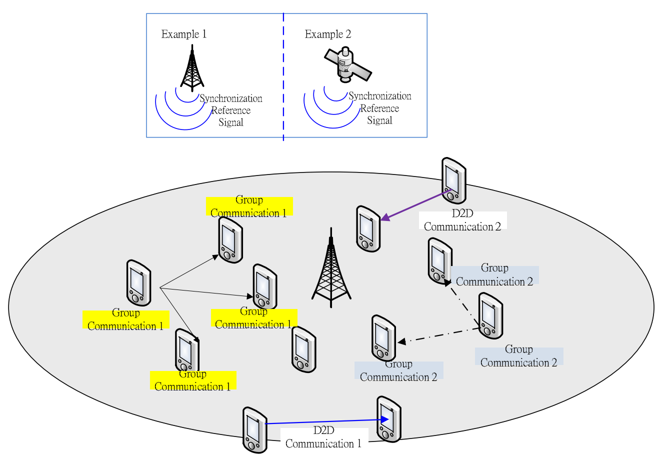


Figure 22: LTE D2D scenarios Within Network Coverage

In the case of out of cell coverage situation, UEs may communicate directly with each other via LTE technology, and the communication may happen with or without network assistance (e.g. signaling and control).

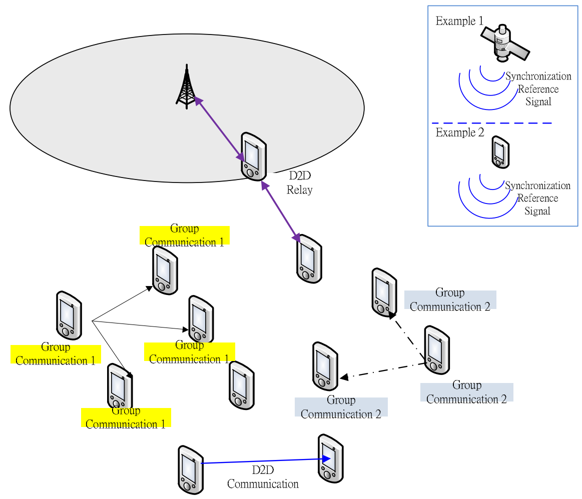


Figure 23: LTE D2D scenarios Outside Network Coverage

Furthermore, 3GPP defines a UE relaying feature which is used for public safety scenarios. This feature is applicable in situations such as UE-to-Network relaying (when a UE is relayed to the network by a UE with relaying capabilities called UE-Relay) or UE-to-UE relaying (when a UE is relayed to another UE with the help of a UE Relay).

2.6.1 D2D Unicast communications

This scenario will address two issues:
- efficient radio resource allocation schemes, and
- optimal control channel design

for 2D2 Unicast communications fitting all situations (inter-cell communication, in and without cell coverage, extension with UE relay).

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	D2D Unicast communications
Task	T5.2
Network topology	LTE-A Macro cells UEs in and out of coverage UE Relays to extend cell coverage
Radio Access Technology (-ies)	LTE-A
Nature of small cells	NA
Environment	Dense urban // Urban
Context	Outdoor
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE-A licensed bands
Density of small cells	NA
Backhaul	NA
Propagation/channel model	Official 3GPP channel models for D2D (when available)[32]
Mobility model	Variable mix of static slow and high mobility users
Traffic model	Periodic traffic, variable rate (10Hz, 5Hz, 2Hz, 1Hz, < 1Hz) Small to medium packet size (up to 300 bytes)
Services	Voice: %100 of users Data: %100 of users
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Cell throughput, cell edge throughput
Description of the problem to be solved (target) and proposed method for solution	Efficient radio resource allocation schemes fitting all situations (inter-cell communication, in and without cell coverage, extension with UE relay) Control channel for optimal D2D unicast communications
Evaluation method	System level analysis

Links with other work packages: none

2.6.2 D2D broadcast communications

This scenario addresses various challenges associated with D2D broadcast communications:

- definition of an optimal waveform
- Enabling the spatial reuse of resources dedicated to D2D communications by other D2D transmissions
- Optimization of UE relays using eMBMS technology for broadcast communications with out-of coverage UEs

UEs broadcast messages to other UEs that can be within the same cell (area controlled by a single eNodeB) or in different cells (areas possibly controlled by multiple eNodeBs).

Local services (D2D communications that take place within an area smaller than a cell) are locally announced by the service announcer and take place on a local set of resources that can be reused.

Services within a whole cell area (D2D communications that take place within an area controlled by the same eNodeB) can be announced and receive dedicated resources directly from the eNodeB.

Services on a wide area (D2D communications between users in areas controlled by multiple eNodeBs) will require a wide area resource allocation. These resources will be allocated by the service announcer in the specific area of interest.

These services could also work in case of temporary loss of eNodeB coverage and UE relay feature can give services to UEs which are out of coverage

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	D2D broadcast communications
Task	T 5.2
Network topology	LTE macro cells
Radio Access Technology (-ies)	LTE / LTE-A
Nature of small cells	NA
Environment	Urban/Highway
Context	Outdoor (for traffic safety applications/proximity safety service)
Inter-site distance	Optimally: inter-site should lead to UEs to always be under coverage of 1 eNB (Macro)
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	NA
Backhaul	EPC should coordinate resource allocations between eNBs similarly to eMBMS (note: no synchronization of transmitted data is required)
Propagation/channel model	Official 3GPP channel models for D2D (when available)[33]
Mobility model	Variable mix of static slow and high mobility users
Traffic model	Periodic traffic, variable rate (10Hz, 5Hz, 2Hz, 1Hz, < 1Hz) Small to medium packet size (up to 300 bytes)
Services	Traffic safety applications exploiting Vehicle-to-Vehicle LTE Direct broadcast communications (proximity safety services). Application to ITS (Intelligent Transportation Systems) and Smart Cities.
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	- Aggregated throughput - Successful packet delivery rate - Transmission range - Fairness - Delay
Description of the problem to be solved (target) and proposed method for solution	1) Maximize number of supported broadcast UEs with a given MAC-level probability of successful reception (collision avoidance) – Adapting TX rate (periodicity), – Adapting TX power 2) Given a UEs distribution in space, maximize the transmission range given a fixed pool of resources dedicated to D2D broadcast transmissions
Evaluation method	Analytic MAC level simulation/emulation

Links with other work packages: none

2.6.3 D2D communications for overloaded networks

This scenario will consist of a central loaded cell surrounded by a group of clusters of D2D enabled UEs. In each cluster there is a pair of D2D UEs wishing to communicate with each other. The eNB has no spare spectrum dedicated to D2D communications and so it must manage a spectrum reuse strategy to allow D2D communications and guarantee the QoS of all cell-center and cell UEs at the same time. The eNB spectrum management strategy will use/share the uplink spectrum as the spectrum is less loaded in uplink than in downlink (ongoing 3GPP discussions on the approval of such a spectrum sharing in the context of D2D study item for the upcoming release). The goal of eNB D2D management is to maximize the cell throughput gain by introducing D2D communications while preserving the QoS of all cell UEs (cell-center as well as cell edge).

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	D2D communications for overloaded networks
Task	T5.2
Network topology	Macro cell
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE D2D
Environment	Dense urban
Context	Outdoor
Inter-site distance	500-1000 meters for macro-to-macro
Frequency deployment strategy	Co-channel deployment.
Frequency bands	LTE licensed bands
Density of small cells	
Backhaul	Ex: Ideal OR non-ideal channel gain beedback
Propagation/channel model	Shadowing: log-normal distribution Fast fading: Rayleigh
Mobility model	users at 3 km/hr
Traffic model	Hotspot traffic and Traffic constant
Services	Voice and Data
Number of transmit/receive antennas (for MIMO schemes)	1x1
KPIs, metrics involved	Avg. cell throughput
Description of the problem to be solved (target) and proposed method for solution	Maximizing cell throughput through intelligent interference management and resource allocation for spectrum sharing between cell users and D2D users.
Evaluation method	Link level simulations and single cell System level simulations

Links with other work packages: none

2.7 Deployment scenario 7: Carrier Aggregation (CA)

Deployment scenario 7 gathers the 4 following scenarios involving carrier aggregation:

1. Carrier aggregation using reconfigurable RF front-ends
2. Antenna Design: small antenna for femto cell, compatible with 4G systems bandwidths
3. Coordinated carrier aggregation in campus of femto base stations
4. Multi-Flow Carrier Aggregation

2.7.1 Carrier aggregation using reconfigurable RF front-ends

Within this scenario, a reconfigurable RF front-end is proposed to implement carrier aggregation. Using this technique the bandwidth can be extended up to 100MHz by aggregating up to five component carriers. CA appears as a key enabler in 3GPP Release 10 to support wider transmission bandwidth than 20MHz specified in 3GPP Release 8/9. As a result, it can improve network efficiency and user performance by dynamically allocating traffic across the entire available spectrum. This freedom to combine up to five carriers provides a reconfigurable and flexible bandwidth in order to support the demanded data (video, message, e-mail, phone calls, etc).

In order to implement CA, specific RF front-ends are required to support up to five carriers in the same band, identified as intra-band CA, or different bands, identified as inter-band CA. The study will be based on the design of reconfigurable RF front-ends to support CA, evaluating the RF requirements and constraints.

Various potential CA deployment scenarios have been described in 3GPP[34]. In Figure 24 , there are some examples that could be applied in macro cells or small cells. There are two possible cells, F1 and F2, working on the same base station. In the first example (a), F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. A likely scenario is when F1 and F2 are of the same band. Therefore RF front-end should support intra-band CA. It is expected that aggregation is possible between overlaid F1 and F2 cells. In the second example (b), F1 and F2 cells could also be co-located and complementary where F2 is directed to the cell boundaries of F1 so that the cell edge throughput is increased. Then it is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps. A likely scenario is when F1 and F2 are of different bands. In this deployment, RF front-end should support inter-band CA.

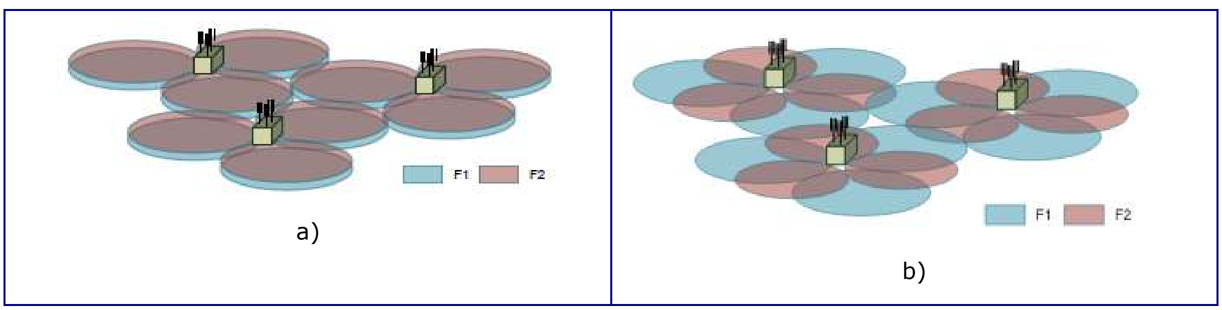


Figure 24: CA deployment scenario a) providing nearly the same coverage and b) improving cell edge throughput

3GPP also describes CA deployment scenarios for HetNets (Figure 25). In the first example (a), F1 provides macro coverage and F2 is used to improve throughput at hotspots, offloading the macro cell. Mobility is performed based on F1 coverage and a likely scenario is when F1 and F2 are of different bands. A more challenging CA deployment scenario is presented in the second example (b), because the same frequency F2 is used by the base station and the hotspots so some limitations are required due to the inter-cell interference.

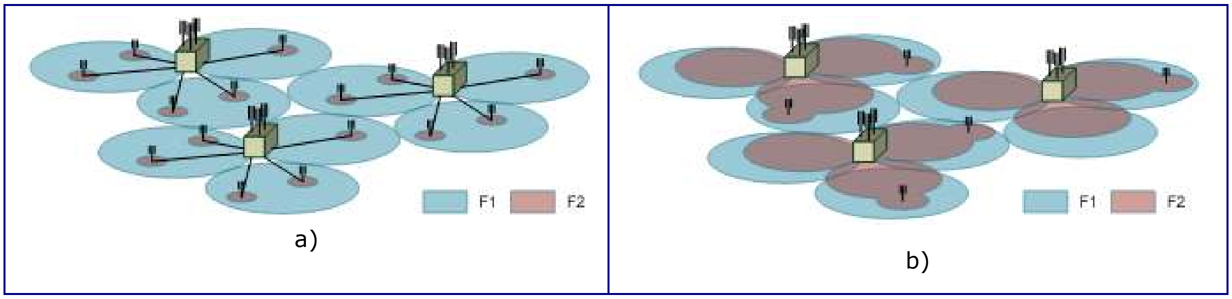


Figure 25: CA deployment scenario for HetNets

To be able to perform all these CA deployment scenarios, a reconfigurable RF front-end is an appropriate solution to adapt the communication to the different configurations.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Carrier aggregation using reconfigurable RF front-ends
Task	T3.4
Network topology	Macro cells // Small cells // HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A pico / femto
Environment	Dense urban // Urban
Context	Outdoor
Inter-site distance	NA
Frequency deployment strategy	Carrier aggregation deployment
Frequency bands	LTE-A licensed bands
Density of small cells	Dense
Backhaul	Ideal backhaul between small cells
	Ideal backhaul between small cells and macro cells
	Ideal backhaul for all other interfaces
Propagation/channel model	Path loss: Okumura-Hata or Veh-A etc.
Mobility model	Static
Traffic model	Real daily traffic patterns
Services	Voice: 100% of users Data: 100% of users
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Cell throughput, cell edge throughput
Description of the problem to be solved (target) and proposed method for solution	Provide reconfigurable RF front-ends to implement different CA deployment scenarios and improve cell throughput, cell edge throughput.
Evaluation method	System level analysis

Links with other work packages: WP7 where a hardware development on carrier aggregation will be done

2.7.2 Antenna Design: small antenna for femto-cell, compatible with 4G systems bandwidths

Similar to what has been described in section 2.7.1, an antenna is needed that adapts to the various CA configurations. The challenge posed by such a broadband antenna relies in coping with the lowest frequencies of the band: indeed LTE-A has been allowed the 790-862MHz band. In addition to that, we want to forecast the use of TV White Space (TVWS) bands, i.e. 698-790MHz by future systems. At such low frequencies reducing the size of the antenna is a challenge, all the more so if the transmission bandwidth is large. Therefore, frequency agility will be considered at the lowest frequency bands.

The antenna will be connected to the RF developed in section 2.7.1, and measured in an anechoic chamber. A prototype will be developed in WP7.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Antenna Design: small antenna for femto-cell, compatible with 4G bandwidths
Task	T3.4
Network topology	Small cell only
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE femto
Environment	Offices , Homes/flats etc…
Context	Indoor
Inter-site distance	NA
Frequency deployment strategy	Carrier aggregation
Frequency bands	LTE licensed bands,TV whitespaces
Density of small cells	NA
Backhaul	NA
Propagation/channel model	3GPP SCME[35]
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	1
KPIs, metrics involved	Radiation pattern.
Description of the problem to be solved (target) and proposed method for solution	Small antenna able to cope with the lowest frequency bands of LTE
Evaluation method	Anechoic chamber measurements

Links with other work packages: none

2.7.3 Coordinated carrier aggregation in campus of femto base stations

In this scenario we will evaluate a technique to improve the throughput of carrier aggregation capable UEs by the means of coordinated multi- point transmission (CoMP). The carrier aggregation capable UE is receiving in this case datas and/or control from multiple base stations that coordinate their transmission such as not to use the same resources for the transmission to the UE. This will ensure transparent operation for the UE and reduce the interference arising from coordinated multipoint transmission.

The deployment scenario considered for this study is a dense group (campus) of femto base stations that are deployed eventually under the coverage of single macro base station.

This scenario is applied also for the distributed synchronization study that will be proposed in Task 4.4. In this case we will have a campus of femto base stations that may be embedded into a network of 19 tri-sector macro base stations we have presented in section 0.

The femto campus scenario and the coordinated carrier aggregation are further described in the figure below

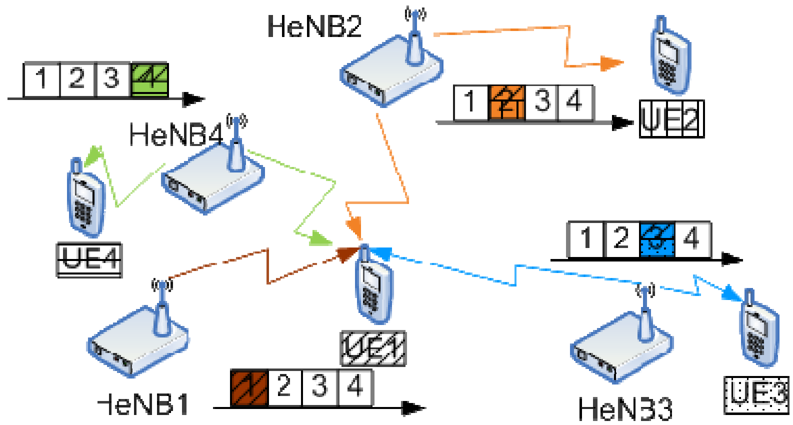


Figure 26: Coordinated carrier aggregation

Details of the femto campus simulation scenario is given by the table below

Scenario aspect	**Description**
Title	Coordinated carrier aggregation in campus of femto base stations
Task	T4.4
Network topology	Coordinated group of femto base stations (campus)
Radio Access Technology (-ies)	LTE-A
Nature of small cells	LTE-A Pico
Environment	Dense urban
Context	Outdoor
Inter-site distance	Random deployment of the campus
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Dense/highly dense campus
Backhaul	ADSL non ideal backhaul
Propagation/channel model	Path loss: outdoor femto model of TR36.814[36] Shadowing: Fixed Fast fading: none
Mobility model	Static to low mobility UEs
Traffic model	Spatial Poisson distribution with higher intensity around the pico cells (as in 3GPP TR 36.814[37]).
KPIs, metrics involved	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Description of the problem to be solved (target)	Coordinated carrier aggregation in campus of femto base stations.
Evaluation method	System level simulations

Links with other work packages: The scenario is used in T4.4 as baseline for the evaluation of the coordinated carrier aggregation. The scenario have link with WP6 since it may lead to signaling over X2 and new coordination node for finding the CCs and PCCs.

2.7.4 Multi-Flow Carrier Aggregation

We look at the problem of single vs. multi-flow carrier aggregation in which users receive different flows coming from different tiers. The challenge lies in judiciously selecting flows and tiers on different component carriers along with suitable power levels. The considered baseline is the single flow when users receive one flow from the same tier. Different tradeoffs will be identified as well as design guidelines as to what mode is preferred and under which network conditions.

The details of the scenario are summarized in the table below:

Scenario aspect	**Description**
Title	Multiflow carrier aggregation
Task	T4.4
Network topology	HetNet (macro + outdoor pico)
Radio Access Technology (-ies)	LTE(-A)
Nature of small cells	LTE pico/micro
Environment	Urban
Context	Both outdoor and indoor areas
Inter-site distance	500 m for macro
Frequency deployment strategy	Carrier aggregation
Frequency bands	LTE licensed bands
Density of small cells	Uniform and non-uniform hotspots
Backhaul	X2
Propagation/channel model	3GPP Path loss model for macro and small cells as specified in TR 25.814[38], TR 36.814[39]. Lognormal shadowing with exponential spatial correlation for all links (std and correlation distance will vary). No fast fading for any of the links.
Mobility model	Static users
Traffic model	Full buffer
Services	Various QoS classes
Number of transmit/receive antennas (for MIMO schemes)	1x1 (downlink)
KPIs, metrics involved	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity) Total network power consumption (per hour) kW/km2 Daily energy consumption (accumulated over 24 hours)
Description of the problem to be solved (target) and proposed method for solution	Single flow vs. multi flow carrier aggregation optimization problem as a function of traffic load, interference levels.
Evaluation method	System level simulations

Links with other work packages: none

2.8 Deployment scenario 8: HSPA

Deployment scenario 8 gathers the following 2 scenarios involving HSPA communications:

1. Macro densification for system capacity/performance
2. Deployment optimization of Heterogeneous networks in urban/suburban environments

2.8.1 Macro densification for system capacity/performance

This scenario will be used to evaluate the performance of a densified HSPA macro network. The obtained results will be compared to the performance of the different kinds of heterogeneous HSPA network deployments.

The system simulations are assumed to be dynamic where user generation, user mobility, traffic model and RRM is assumed to interact dynamically and are modelled at least on the TTI level.

Main assumptions and simulation guidelines should be based in 3GPP case 1 (3GPP TR 36.814, v9.0.0).

The mobility signaling must be considered in this scenario and a call drop model based on the failure to deliver critical signal should be in place as well as the signaling bearer prioritization with respect to user plane data.

The details of this scenario are described in the table below.

Scenario aspect	**Description**
Title	Macro densification for system capacity/performance
Task	T4.1
Network topology	Macro only
Radio Access Technology (-ies)	HSPA
Nature of small cells	NA
Environment	Urban or sub-urban
Context	Outdoor areas
Inter-site distance	500-150 meters (urban) 1732-150 meters (sub-urban)
Frequency deployment strategy	Single carrier co-channel deployment
Frequency bands	UMTS licensed frequency bands
Density of small cells	NA
Backhaul	Non-ideal (Iub)
Propagation/channel model	3GPP case 1 (3GPP TR 36.814, v9.0.0), no LOS component with shadow fading.
Mobility model	Straight random direction movement. Speed: 3, 30, 60, 90, 120 km/h
Traffic model	3GPP FTP model 1 with packet size equal to 500 kBytes and several intensities
Services	100% data (FTP)
Number of transmit/receive antennas (for MIMO schemes)	No MIMO configured
KPIs, metrics involved	Average throughput for the worst 5^{th} percentile of the users Offered area traffic, served area traffic Average throughput considering all the users User drop rate Noise rise level
Description of the problem to be solved (target) and proposed method for solution	Increase the total system performance/capacity by macro densification
Evaluation method	System level simulations

Links with other work packages: none

2.8.2 Deployment optimization of Heterogeneous networks in urban/suburban environments

This scenario will be used to estimate the performance of different types of heterogeneous HSPA network deployments.

The system simulations are assumed to be dynamic where user generation, user mobility, traffic model and RRM is assumed to interact dynamically and are modeled at least on the TTI level. Main assumptions and simulation guidelines should be based on 3GPP case 1 (3GPP TR 36.814, v9.0.0).

The low-power nodes can be located according to hotspot traffic or uniform random distributed locations within given binding conditions. A low-power node (LPN) can create a cell by its own or be part of a combined cell scheme, where the LPN would be recognized by the UE as one of several transmission (and/or reception) points of one specific cell. For example, a macro cell might contain several LPNs that act as distributed remote radio units (RRU) for the main macro unit, and operate with lower power compared to the macro cell. Also a LPN could form its own cell with at least one carrier in the same frequency than the macro layer (co-channel deployment).

The mobility signaling must be considered in this scenario and a call drop model based on the failure to deliver critical signal should be in place as well as the signaling bearer prioritization with respect to user plane data.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Deployment optimization of Heterogeneous networks in urban/suburban environments
Task	T4.1
Network topology	HetNet (macro + outdoor low-power node)
Radio Access Technology (-ies)	HSPA
Nature of small cells	HSPA low-power node
Environment	Urban and sub-urban
Context	Outdoor only
Inter-site distance	500 m for macro
	Irregular for the LPN layer: • Hotspot deployment (within traffic clusters). • Random deployment (75m minimum distance between LPN and macro cell, 40m minimum distance between LPNs)
Frequency deployment strategy	Single carrier Co-channel deployment
Frequency bands	UMTS licensed bands
Density of small cells	Sparse to dense (1-16 LPNs per macro)
Backhaul	Non-ideal Iub and ideal RRU interface
Propagation/channel model	3GPP case 1 (3GPP TR 36.814, v9.0.0), no LOS component with shadow fading.
Mobility model	Straight random direction movement. Speed: 3, 30, 60, 90, 120 km/h
Traffic model	3GPP FTP model 1 with packet size equal to 500 kBytes Voip traffic (90 sec. conversation, 50% activity and 12.2 kbps codec) Mobile broadband traffic from real network traces as a background load. User generation with several intensities.
Services	100% data (FTP) or 100% VoIP
Number of transmit/receive antennas (for MIMO schemes)	No MIMO configured
KPIs, metrics involved	Average throughput for the worst 5th percentile of the users Offered area traffic, served area traffic Average throughput considering all the users User drop rate Noise rise level
Description of the problem to be solved (target) and proposed method for solution	Configure the optimal type of Heterogeneous deployment according to traffic, environment and load characteristics of the system.
Evaluation method	System level simulations

Links with other work packages: none

2.9 Deployment scenario 9: Generic multi-cell/Technology agnostic

Deployment scenario 9 gathers the following 14 technology agnostic scenarios involving a generic multi-cell deployment:

1. Conversion block
2. Energy efficiency strategies over different power levels in the power amplifier
3. Extension of Performance Evolution for Femto -> Small Cells
4. Secure communication with imperfect CSIT
5. Flexible interference management schemes for downlink communications
6. Flexible interference management schemes for downlink communications
7. Theoretical Performance Analysis of Heterogeneous Cellular Networks
8. Relay-aided interference mitigation
9. Asymptotic Performance of Hetnets under Dynamic Traffic
10. Theoretical analysis for linearity and power efficiency trade-off in transmitters base stations
11. Distributed RRM Strategies without information exchange between the transmitters
12. Joint processing CoMP with limited backhaul and spatial CSIT allocation design
13. Interference alignment for large dense network
14. Broadcast Channel Feedback in Cooperated Multiple Antenna Systems

2.9.1 Conversion block

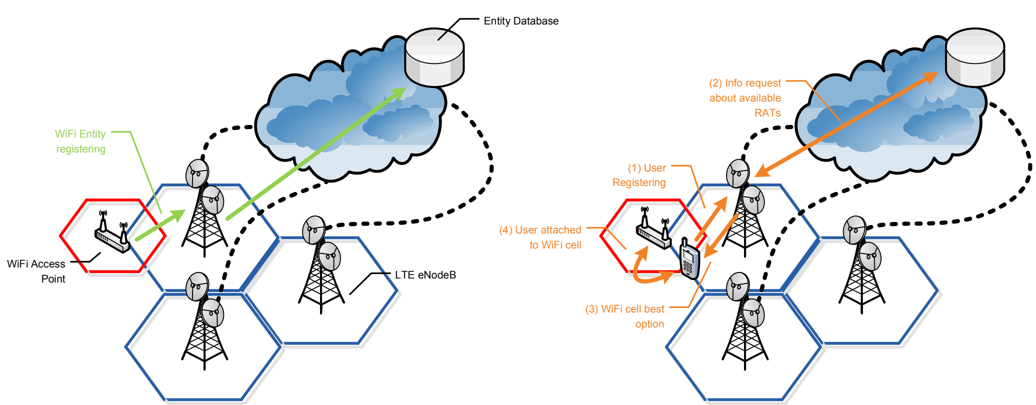
This scenario is set to enable managing the intra-LTE offloading via the definition and implementation of a middleware decision module. This module will be able to interact with the existing user and spectrum databases, obtaining from the needed information so as to allocate always a given resource to the best place. All RATs will be listed and categorized depending on their current status, and new ones can be added. Users will be managed, and the system will respond to a user petition with the best possible RAT available nearby (Figure 27).

The middleware will be based on IP and above protocols, so the network layout, frequency, mobility etc. of the underlying deployment is transparent.

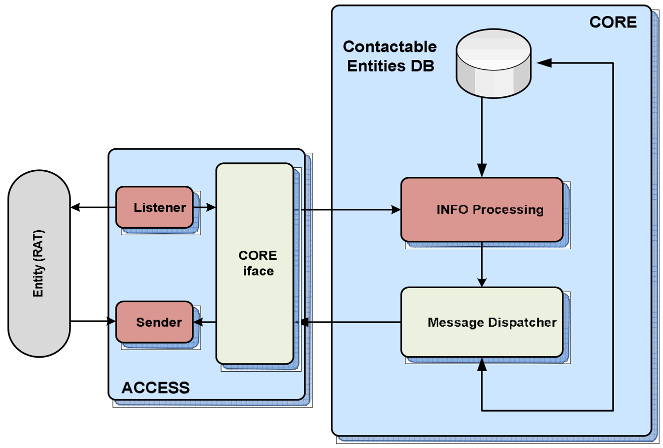
One important assumption for the method is that is must maintain a desired level of QoS. It cannot be compromised by the changes triggered by this adaptation layer.

Transparent exchange of information must be assured, enabling fast and simple addition of new entities and making all information available to any of them. This is guaranteed by enabling a publisher/subscriber architecture.

Finally, the design will be done in line with IEEE802.21 standard requirements.



(a)



(b)

Figure 27: (a) System layout, (b) Conversion block details

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Conversion block
Task	T4.1 & T4.2
Network topology	NA
Radio Access Technology (-ies)	
Nature of small cells	
Environment	
Context	
Inter-site distance	
Frequency deployment strategy	
Frequency bands	
Density of small cells	
Backhaul	
Propagation/channel model	
Mobility model	
Traffic model	
Services	
Number of transmit/receive antennas (for MIMO schemes)	
KPIs, metrics involved	Overhead and delay introduced by the adaptation layer
Description of the problem to be solved (target) and proposed method for solution	Offloading and load balancing strategies (eNBs <--> small cells) to improve resource utilization. Managing the Intra-LTE and Inter-RAT offloading via the definition and implementation of a middleware.
Evaluation method	Software simulation

Links with other work packages: As it is a mechanism envisaged to be deployed at IP and above layers, it does not imply modifications on the actual behavior of the current LTE network. All entities involved in the study should include support to implement this algorithm at software level. Therefore, no other WP interactions are foreseen.

2.9.2 Energy efficiency strategies over different power levels in the power amplifier

This scenario presents a technique to adapt the bias point of the power amplifier according to the traffic load and output power requested, optimizing the power consumption in this stage. This solution could provide significant energy savings in the base station radio equipment, because the power amplifier is one of the most power consuming components.

During a day, the power consumption in a base station is related to the traffic load. Normally, the power amplifier is designed to support a maximum traffic load in the coverage area and provides the highest energy efficiency at maximum RF output power, i.e. at maximum traffic load. Nevertheless, when the traffic load decreases, lower RF output power levels are required and the energy efficiency becomes worse due to the PA power consumption characteristics. For that reason, the base station wastes energy in medium and low load situations. An innovative solution proposes a technique to dynamically adapt the power level in the PA to improve the energy efficiency in a base station. The adjustment is done by modifying the operating point in the PA using a dynamic supply voltage to adapt the RF output power level.

This technique is applied at hardware level, therefore several scenarios could be supported. The energy efficiency improvement will be significant at low traffic load because the required RF output power level decreases and the PA could reduce its output power level to satisfy traffic load demand.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Energy efficiency strategies over different power levels in the power amplifier
Task	T4.3
Network topology	Macro cell // Small cell (activity at hardware level)
Radio Access Technology (-ies)	LTE-A and LTE
Nature of small cells	LTE pico/micro/femto
Environment	Dense urban // Urban // Suburban // Rural
Context	Outdoor
Inter-site distance	Dynamic
Frequency deployment strategy	NA
Frequency bands	LTE/LTE-A licensed bands
Density of small cells	Dense OR Sparse
Backhaul	NA
Propagation/channel model	NA
Mobility model	Static
Traffic model	Real daily traffic patterns
Services	Voice: 100% of users Data: 100% of users
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Energy efficiency, throughput, average output power
Description of the problem to be solved (target) and proposed method for solution	Adjust the RF operation point in base stations to traffic load, optimizing the power consumption for a requested output power. Study focuses on power amplifier design.
Evaluation method	Circuit level analysis

Links with other work packages: none

2.9.3 Extension of Performance Evolution for Femto -> Small Cells

In this scenario the aim is to explore the utilization of smart phones for monitoring, symbiosis, and performance evaluation in small cells networks, and the evolution of these, e.g. hetnets. This could be e.g. smart phones for location verifications, or explore the possibility and the opportunity to save energy in mobile networks with smart phones, or to increase capacity in mobile networks when users are indirectly guided to optimize their terminal locations

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Extension of Performance Evolution for Femto -> Small Cells
Task	T.6.2
Network topology	Macro cell/ Small cell evolutions and HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A or HSPA WiFi
Nature of small cells	LTE or HSPA pico/micro/femto WiFi
Environment	Business District
Context	Feedback evaluation of Smartphone's as a complementive performance management and monitoring in hetnet networks
Inter-site distance	NA
Frequency deployment strategy	NA
Frequency bands	LTE or HSPA licensed bands WiFi unlicensed bands
Density of small cells	NA
Backhaul	NA
Propagation/channel model	Path loss: Okumura-Hata (parameters) Shadowing: lognormal with exponential spatial correlation Fast fading: Rayleigh
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Smart phones and Smart phone api's
Description of the problem to be solved (target) and proposed method for solution	Study the utilization of smartphones in performance evolution in HetNets and the impact on planning and optimization processes. In conjunction with current sources of information e.g. • Drive test data, OSS performance data • As complementing source of information • In conjunction with new monitoring capabilities offered by HetNets
Evaluation method	Agile method where evaluations are done with few selected use cases. Currently, use cases are the following: • Utilization of smartphones measurements in verification of localizations architecture concepts • Utilization of smart phones for user and network oriented symbiosis e.g. guidance of user based on performance evaluation

Links with other work packages: none

2.9.4 Secure Communication with Imperfect CSIT

This scenario aims at investigating the performance of a broadcast or interference channel with secrecy constraint, i.e. the message for one user should be kept secret to the others. The channel state information is assumed to be imperfect at the transmitter's side. We would like to investigate the loss of throughput due to these additional constraints. More importantly, the efficient schemes in this context are expected to be quite different from the conventional ones without the constraints.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Secure communication with imperfect CSIT
Task	T3.1
Network topology	Cellular network with single or multiple cells
Radio Access Technology (-ies)	NA
Nature of small cells	NA
Environment	NA
Context	NA
Inter-site distance	NA
Frequency deployment strategy	NA
Frequency bands	NA
Density of small cells	NA
Backhaul	NA
Propagation/channel model	Path loss: To be determined Fast fading: Rayleigh model
Mobility model	Static
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Degrees of freedom region, capacity
Description of the problem to be solved (target) and proposed method for solution	Characterization of the inner and outer bounds on the degrees of freedom region of this model and identification of the optimal transmission strategy, with the use of information-theoretic tools
Evaluation method	Analytical/theoretical

Links with other work packages: none

2.9.5 Flexible interference management schemes for downlink communications

This scenario aims at investigating PHY-layer abstraction algorithms for closed-loop MIMO systems with limited feedback under the assumption of turbo processing at the destination (iterative (turbo) LMMSE-IC based receivers and variants). The objective is to evaluate the accuracy of existing Link to System interfaces (L2S) and design new L2S interface adapted to MCS sets based on more powerful codes (e.g., turbo codes or LDPC codes), coding across antennas (STBICM), and spatial precoding (e.g., antenna selection).

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Flexible interference management schemes for downlink communications
Task	T3.3
Network topology	macro cells or small cells
Radio Access Technology (-ies)	LTE-A
Nature of small cells	NA
Environment	General
Context	NA
Inter-site distance	NA
Frequency deployment strategy	NA
Frequency bands	LTE licensed bands
Density of small cells	low
Backhaul	Ideal
Propagation/channel model	Shadowing: lognormal Path loss: any model Fast fading: Rayleigh or Markov model
Mobility model	static
Traffic model	constant
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Outage, prob of errors, average cell throughput
Description of the problem to be solved (target) and proposed method for solution	Cross-layer design and optimization for LTE and beyond, based on the assumption of turbo processing at the destination (iterative joint LMMSE-IC and decoding), flexible interference management concept
Evaluation method	Semi Analytical

Links with other work packages: none

2.9.6 Theoretical Performance Analysis of Heterogeneous Cellular Networks

This scenario aims to analyze the performance of Heterogeneous networks, in terms of key measures such as coverage probability and area spectral efficiency, by taking into account the network geometry and the spatial randomness. The main focus will be to characterize the interference statistics and dynamics and to quantify the performance gains. Advanced PHY technologies (e.g. MIMO, cooperative transmission, interference alignment, etc - related to WP3 or even biasing, cell expansion, etc) will be analyzed and their effect on the network performance will be investigated. Backhaul models will be considered in our framework in order to provide a more complete characterization of network performance.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Performance analysis of Heterogeneous Cellular Networks
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	LTE-A compliant
Nature of small cells	The analysis will be for general parameters (adaptation of which results in pico, femto, macro, etc)
Environment	Dense urban
Context	Outdoor and indoor
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment or cognitive/flexible/adaptive frequency allocation
Frequency bands	NA
Density of small cells	Full range of SC density (sparse to low)
Backhaul	Wired and wireless backhaul (perfect and imperfect)
Propagation/channel model	Rayleigh or General (Gamma) small scale fading Distance dependent pathloss attenuation
Mobility model	Low to no mobility
Traffic model	Constant
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Coverage probability, area spectral efficiency (throughput), average spatial rate
Description of the problem to be solved (target) and proposed method for solution	- Quantify the interference statistics and characterize the performance taking into account spatial randomness and uncoordinated interference. - Propose mechanisms to enhance the performance (coverage, rate)
Evaluation method	Analytical/Theoretical

Links with other work packages: none

2.9.7 Relay-Aided Interference Mitigation

This scenario aims at investigating the performance of an interference channel with a relay. More precisely, the objective is to provide an analysis of the capacity region of such a channel model in the context of a cellular network. Even though this study is theoretical, it provides an insight on the roles of a relay for interference mitigation and the kinds of efficient strategies to be used for different channel conditions.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Relay-aided interference mitigation
Task	T3.3
Network topology	Cellular network with infrastructure relay
Radio Access Technology (-ies)	NA
Nature of small cells	General parameters
Environment	NA
Context	NA
Inter-site distance	NA
Frequency deployment strategy	NA
Frequency bands	NA
Density of small cells	NA
Backhaul	NA
Propagation/channel model	Path loss: To be determined Fast fading: Rayleigh model
Mobility model	Static
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Capacity region
Description of the problem to be solved (target) and proposed method for solution	Characterization of the inner and outer bounds on the capacity region of this network, with the use of information-theoretic tools
Evaluation method	Analytical/theoretical

Links with other work packages: none

2.9.8 Asymptotic Performance of HetNets under Dynamic Traffic

This scenario aims at investigating the impact of bursty traffic on the performance of HetNets. More precisely, the objective is to provide an asymptotic performance analysis in the context of heavy traffic, i.e. when the traffic arrival rates are pushed very close to the capacity region boundary. This scenario allows an easier analysis (and better understanding) of the delay and queue stability/overflow due to the phenomenon of state space collapse. Even though this study is theoretical, it allows designing advanced stable resource allocation strategies that ensure queue/delay outage constraints and therefore stringent QoS constraints.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Asymptotic Performance of HetNets under dynamic traffic
Task	T4.1
Network topology	HetNet (overlay of macro cells and small cells)
Radio Access Technology (-ies)	NA
Nature of small cells	General parameters
Environment	NA
Context	NA
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment or cognitive/flexible/adaptive frequency allocation
Frequency bands	NA
Density of small cells	Low
Backhaul	Ideal
Propagation/channel model	Path loss: tbd Fast fading: Rayleigh or Markov model with finite number of states
Mobility model	Static
Traffic model	Dynamic traffic arrival (i.i.d.)
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Queue stability, Avg. cell throughput
Description of the problem to be solved (target) and proposed method for solution	Find asymptotic limits that capture the dynamic evolution of the queue length of each transmitter and define strategies that minimizes the queue outage/delay
Evaluation method	Analytical/theoretical

Links with other work packages: none

2.9.9 Theoretical analysis for linearity and power efficiency trade-off in transmitters base stations

Power amplifiers consume most of the power of macro base stations transmitters. Power amplifiers have low efficiencies in their linear areas and high efficiencies close to their saturations, i.e. in nonlinear areas. Some recent communication standard set up a peak factor reduction technique (to enhance the power amplifier efficiency) followed by a linearization (to linearize the power amplifier characteristic). So in such a scenario, the performance of the linearization is influenced undoubtedly by the peak factor reduction method. In this contribution, we study the Error Vector Metric (EVM) metric and evaluate a closed form regarding the performance of both the peak factor reduction technique and the linearization. We choose the pre-distortion as a linearization technique and define a pre-distortion error. Assuming that the baseband OFDM signal is characterized as a complex Gaussian process we will first study the distribution of the resulted signal after peak factor reduction. Then, we will derive theoretical expressions of the first and second order moments of the pre-distortion error and show that the error depends mainly on the peak factor of the signal after peak factor reduction method and on the pre-distortion quality. This expected result is a trade-off between linearization and crest factor performance.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Energy efficiency enhancement strategies in macro cells power amplifiers
Task	T4.3
Network topology	Macro cell
Radio Access Technology (-ies)	LTE-A and LTE
Nature of small cells	NA
Environment	Dense urban // Urban // Suburban // Rural
Context	Outdoor
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE/LTE-A licensed bands
Density of small cells	NA
Backhaul	NA
Propagation/channel model	NA
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	NA
KPIs, metrics involved	Power amplifier efficiency Interference level Error Vector Magnitude
Description of the problem to be solved (target) and proposed method for solution	Trade-off between linearity and power amplifier efficiency. Joint crest factor and linearity approach at power amplifier level
Evaluation method	System level simulations

Links with other work packages: none

2.9.10 Distributed RRM Strategies without information exchange between the transmitters

This scenario aims at developing advanced distributed RRM strategies that ensure the stability of the network (in terms of queue stability) in the context of dynamic traffic arrival. The transmitters (for instance base stations, access points, etc.) do not exchange any information between each other.

Furthermore, we will develop advanced learning-based RRM frameworks that allow users to learn and improve their network utilities (rate, QoS, QoE, probability of success, etc.) in HetNets based on local information and noisy measurements.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Distributed RRM strategies
Task	T4.4
Network topology	Any (multi-cell, Ad-Hoc, etc.)
Radio Access Technology (-ies)	Generic
Nature of small cells	General parameters
Environment	NA
Context	NA
Inter-site distance	NA
Frequency deployment strategy	Co-channel deployment or cognitive/flexible/adaptive frequency allocation
Frequency bands	NA
Density of small cells	Low
Backhaul	Ideal
Propagation/channel model	Path loss: to be determined Fast fading: Rayleigh or Markov model with finite number of states
Mobility model	Static
Traffic model	Dynamic traffic arrival (i.i.d.)
Services	
Number of transmit/receive antennas (for MIMO schemes)	General parameter
KPIs, metrics involved	Outage prob, Avg. cell throughput
Description of the problem to be solved (target) and proposed method for solution	Develop distributed RRM strategies that minimize the outage or maximize a network utility function (QoS, QoE)
Evaluation method	Analytical/theoretical

Links with other work packages: none

2.9.11 Joint processing CoMP with limited backhaul and spatial CSIT allocation design

In this scenario, we will consider a K-cell network operating in the same frequency band, with one single-antenna transmitter (TX) and one single-antenna receiver (RX) in each cell. The TXs share users' data perfectly so as to jointly serve the RXs. The channel state information (CSI) estimate is first fed back from RX to TX in each cell, and further shared among TXs via limited-capacity backhaul links, such that each TX obtains its own estimate of the global multi-user channel, which is different from one another. This CSI configuration is referred to as distributed CSIT setting. With distributed CSIT, two problems are under investigation: 1) analyzing the performance of JP-CoMP transmission with regard to the quality of CSI shared among TXs; 2) designing the spatial CSIT allocation policies among TXs for joint cooperation.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Joint processing CoMP with limited backhaul and spatial CSIT allocation design
Task	T3.1
Network topology	Multi-cell
Radio Access Technology (-ies)	LTE-A and/or 5G
Nature of small cells	NA
Environment	NA
Context	Outdoor
Inter-site distance	NA
Frequency deployment strategy	Full reuse
Frequency bands	NA
Density of small cells	NA
Backhaul	Non-ideal backhaul between cells
Propagation/channel model	Fast fading model + standard distance dependent path loss model
Mobility model	Static
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	Arbitrary
KPIs, metrics involved	Sum rate and/or Degrees of freedom
Description of the problem to be solved (target) and proposed method for solution	Performance analysis of joint processing CoMP with regard to the quality of CSI shared among transmitters; Designing spatial CSIT allocation policies through distance-based approach
Evaluation method	Analytical and simulation (MATLAB)

Links with other work packages: none

2.9.12 Interference alignment for large dense network

In this scenario, we study a large dense cellular network modeled by a K-user MIMO interference channel (IC), where data sharing is not allowed among transmitters (TXs). Instead of global channel state information (CSI) sharing among TXs as considered in conventional interference alignment (IA) model, only incomplete CSIT (i.e., a sub-matrix of the global channel matrix) is available. We aim at designing the CSI allocation policies to preserve IA feasibility while reducing the amount of CSI sharing required at the TXs.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Interference alignment for large dense network
Task	T3.3
Network topology	Multi-cell
Radio Access Technology (-ies)	LTE-A and/or 5G
Nature of small cells	NA
Environment	NA
Context	Outdoor
Inter-site distance	NA
Frequency deployment strategy	Co-channel
Frequency bands	NA
Density of small cells	NA
Backhaul	Non-ideal backhaul between cells
Propagation/channel model	Fast fading model + distance-dependant path loss model
Mobility model	NA
Traffic model	NA
Services	NA
Number of transmit/receive antennas (for MIMO schemes)	Arbitrary
KPIs, metrics involved	Sum rate or Degrees of freedom
Description of the problem to be solved (target) and proposed method for solution	CSI allocation policies design preserving interference alignment feasibility while reducing the amount of CSI sharing required at the transmitters
Evaluation method	Analytical and simulation (MATLAB)

Links with other work packages: none

2.9.13 Broadcast Channel Feedback in Cooperated Multiple Antenna Systems

This scenario evaluates the performance of broadcast feedback in a large dense network.

Via this scenario we study the impact of imperfection in the CSI feedback for multi-cell network MIMO. The objective is also to find the optimum feedback scheme and optimum cluster of base stations that are participating in the CoMP for any set of users.

System level simulations will be carried out extensively to study the scenario. The numerical results of the simulations will be compared with analytical expressions to get more insights into the scenario.

The details of this scenario are described in the table below:

Scenario aspect	**Description**
Title	Broadcast Channel Feedback in Cooperated Multiple Antenna Systems
Task	T3.1
Network topology	Multi cell
Radio Access Technology (-ies)	LTE
Nature of small cells	Pico cells
Environment	Dense urban
Context	Both Outdoor and Indoor UEs
Inter-site distance	500 m ISD for macro cells
	Variable for small cells ISD
Frequency deployment strategy	Co-channel deployment
Frequency bands	LTE licensed bands
Density of small cells	Variable
Backhaul	Both ideal (i.e. typical point to point fiber) and non-ideal backhauls will be considered
Propagation/channel model	Path loss: Generic exponential Shadowing: Fixed Fast fading: Rayleigh
Mobility model	Pedestrian (3 km/h)
Traffic model	Full buffer
Services	High speed data.
Number of transmit/receive antennas (for MIMO schemes)	2X1, 4X1
KPIs, metrics involved	Sum Rate
Description of the problem to be solved (target) and proposed method for solution	Impact of limited feedback and feedback design for CoMP
Evaluation method	Simulations and analytical analysis

Links with other work packages: none

3 Definition of KPIs

Key Performance Indicators (KPI) can be defined as a set of metrics that allow a reliable and complete assessment of network performance in the evaluated scenario. Key performance indicators allow a conclusive comparison of a set of solutions.

The objective of this section is to make a state-of-the art of the existing relevant KPIs and to complement these already existing KPIs with the ones that drive the project innovations toward the desired directions. Since the objective of the project is to move towards a ubiquitous quality of experience, KPIs such as the ratio of the cell-average over the cell-edge spectrum efficiency normalized with respect to the number of users (Jain index[40]) could serve as an interesting basis for improving the existing KPIs. In addition to this, efforts could be made in order to measure the energy efficiency of the techniques that aim at fulfilling this objective of throughput homogeneity over the cell, while classical green metrics measure the energy efficiency of the increase of throughput. These metrics use power and traffic models for the calculation of the consumed power. Models already designed for the Base Stations by previous projects like EARTH[41] or consortiums like Greentouch[42] could be reused.

Investigations will also be made in order to provide a new definition of the capacity that takes into account operator deployment constraints. The capacity could be defined as the maximum cell throughput assuming that a certain criterion is respected for all users, such as a minimum throughput per user.

3.1 KPIs state-of-the-art

Whenever several partners want to cooperate in developing advanced systems, a common understanding of the metrics is necessary in order to compare the results in a well-defined manner. To achieve this, different organizations have proposed a fixed set of evaluation metrics or key performance indicators[43]. In this section the most relevant existing approaches will be presented in order to derive a set of appropriate metrics for the SHARING project, taking into account several different existing classifications.

The existing indicators can be classified according to their high-level functionally (above/beyond technical) as follows:

- Performance related KPIs: Metrics that allow evaluation of the proposed solutions in terms of network and user perceived performance. Some examples are:
    - Spectral efficiency (SE) – measure of performance of a system in relation to the utilized frequency bandwidth.
    - Reliability – measure of the quality of a radio link connection for fulfilling a certain service level.
    - Fairness – measure of performance uniformity within network.
    - Latency – measure of time delay experienced in a system. It can be defined either as one-way or round-trip transmission time.
    - Traffic volume density - traffic volume density describes the total user data volume transferred to/from end-user devices during a predefined time span divided by the area size covered by the radio nodes belonging to the RAN(s)
    - Availability and retainability – measures the percentage of users or communication links for which the QoE requirements are fulfilled within a certain geographical area
    - Quality of Experience (QoE) – measure of user's experience for a given service. This is a more subjective measure that by replacing traditional QoS measures like throughput and delay with appropriate utility functions tries to capture the user perceived end-to-end experience.
    - Quality of Service (QoS) – measure of performance for the provided service, based on measurable quantities.
- Complexity related KPIs: Metrics that allow evaluation of the proposed solutions in terms of resources needed for their application. The related KPIs should consider such factors as:
    - Amount of required control information exchanged between nodes and between nodes and core network elements,
    - Processing effort – measure of computational complexity of the proposed algorithms. This should include e.g. number of required parameters, measurements etc.
    - Energy consumption of a network.
    - Power consumption related to the processing of different modules forming the PHY layer.
- Economic related KPIs: Metrics that allow the evaluation of investments and operating expenses

- Cost (CAPEX and OPEX): The infrastructure part is typically divided into the capital investment to acquire and deploy the network, called Capital Expenditures (CAPEX), and the costs to operate the network, called operational expenditure (OPEX).

The next subsections present the existing KPIs, classified according to their technical functionality. The classification is based on the scale of the technical evaluation, which is also linked to the protocol layers, ranging from small-scale (link-level) to medium- to large-scale (system-level) evaluations.

3.1.1 System-level KPIs

The traffic model in system-level evaluations is known to have a great impact on the performance results. Typically, full-buffer, TUDR or more realistic traffic models that take into account specific service types can be considered.

For evaluations with full-buffer traffic model (data traffic), the following performance metrics are suggested to be considered:

- Mean user throughput.
- Throughput CDF (Cumulative Distribution Function).
- Median and 5% worst user throughput.

For evaluations with bursty traffic model (data traffic), the following performance metrics need to be considered:

- User perceived throughput (during active time), defined as the size of a burst divided by the time between the arrival of the first packet of a burst and the reception of the last packet of the burst
    - Average perceived throughput of a user defined as the average from all perceived throughput for all bursts intended for this user
    - Tail perceived throughput defined as the worst 5% perceived throughput among all bursts intended for a user.
- User perceived throughput CDF (average and/or tail user perceived throughput)
- Percentage of users with 1% or more dropped packets.
- Median and 5% worst user perceived throughput (average and/or tail user perceived throughput).
- Overall average user throughput defined as average over all users perceived throughput.
- Time variations of the throughput in a given scenario and associated traffic and power models.

VoIP capacity evaluations necessitate the following performance metrics to be considered:

- VoIP system capacity in form of the maximum number of satisfied users supported per cell in downlink and uplink.
- System capacity is defined as the number of users in the cell when more than 95% of the users are satisfied.

Metrics[44] for HetNet scenarios should also be considered, since the main focus of SHARING is HetNets. Those metrics can include the conventional KPIs (e.g. Jain Index measuring fairness) as well as HetNet specific KPIs on scalability and deployment aspects such as:

- base station density to provide a given coverage with a given quality in a given area should be evaluated
- the impact of using relay instead (or in addition) to base station will be assessed

Several additional KPIs have been defined for evaluation of HetNets in previous European projects such as Artist4G or WINNER. These are:

- Throughput CDFs for macro UEs and for UEs served by low power nodes (relays).
- Macro cell area throughput (mean and CDF).
- Fraction of total throughput over low power nodes (relays).
- Macro and low power node (relay) serving UE throughput ratio.

Similar metrics are also mentioned by other organizations such as Next Generation Mobile Networks (NGMN) or ITU-R (Radiocommunication). The NGMN Project is an initiative by a group of leading operators to provide a vision for technology beyond 3G.

Additionally, the NGMN evaluation guideline defines a fairness measure and addresses different delay aspects. Therefore, only the metrics not covered by 3GPP are mentioned here. The metrics proposed there are listed here with only short descriptions.

- Fairness: The normalized throughput bound defines a region in the throughput cumulative density function plot.

- Latency
  - Connection setup latency: connection setup latency and the corresponding cumulative density function, guaranteed connection setup latency
  - Radio access transmission latency : one way radio access network transmission latency, the corresponding cumulative density function and 95%ile, radio access network jitter
  - End-to-end packet call latency: cumulative density function and 95%ile of the end-to-end packet call latency.
  - Handover interruption time : interruption time during a handover of real-time and non-real-time services within an NGMN system and between an NGMN system and a different RAN
  - Overhead: Control channel and pilot overhead: percentage of radio resources utilized for signaling, control channels and pilots

The Radiocommunication Sector of the International Telecommunication Union (ITU-R) also defined a set of requirements for future mobile communication systems[45]. The metrics defined there are mainly covered by those mentioned before. A wide range of KPIs have been defined in the WINNER II project[46]. In addition to the standard KPIs as throughput or data rates WINNER II defined metrics considering the resource management and deployment aspects:

- Packet Flow Establishment Time
- Radio resource management related criteria:
  - session rejection rate for new session
  - session drop rate for on-going session
  - trade-off between frequency reuse pattern and system capacity
- Complexity, costs, power consumption

In ITU-T Rec. P.800[47] procedures for the evaluation of the speech quality are provided. The following KPI is defined (and will be used within certain scenarios of the project):

- The Mean Opinion Score (MOS):
  - It provides a numerical indication of perceived quality, expressed as a number in the range 1 (poor quality) to 5 (excellent). Test procedures for the evaluation of MOS basically consist in a set of standard, subjective tests where a pool of listeners in controlled scenarios rate the audio quality of certain test sentences.
  - Even if subjective testing is the most proper method of measuring voice quality; methods for measuring MOS objectively are also available, as for example the E-model originally developed within ETSI and then standardized by the ITU

For **advanced relaying studies**, simulation results can be analyzed and compared with the other concepts using the following system level KPIs:

- The exchange ratio between macro eNBs and relays that provide the same performance in terms of coverage (see also section 6.2.3 on the methodology). Then, knowing the cost ratio between macro eNB and relays it is possible to derive if relay deployment provides cost savings compared to macro eNB-only deployment.
- The exchange ratio between pico and relay that provides the same performance in terms of average throughput (see also section 6.2.3 on the methodology). Then, knowing the cost ratio between pico and relays it is possible to derive if relay deployment is a low cost solution compared to pico deployment.
- Packet delay: The definition of the user plane latency in 4.1.1 can be extended to further measurement points in the transmission chain. This would offer a better view on how the delay is affected by the introduction of the relay node and how the latter would affect the overall delay.
  - End-2-end delay: Measured between the application source and sink.
  - Detailed split of air interface delay: Measured separately for Un and Uu interface, always from sending to receiving PDCP entity.
  - Same as the u-plane latency, these additional KPIs should be computed as
    - Mean value (across time and/or data flows).
    - Jitter (i.e. variance, across time and/or data flows).
    - CDF (per QoS flow class).
- Buffer size:
  - Will be computed as
    - Mean value (across time and/or DRB)
    - CDF (per QoS class).
  - Possible sub-KPIs are

    - Buffer size in the User equipment (UE) for uplink Uu DRBs
    - Buffer size in the relay node (RN) for downlink Uu or uplink Un DRBs
    - Buffer size in the (D)eNB for downlink Uu and Un DRBs.
- Signaling overhead on the Un interface:
  - Were computed as
    - Mean value (across time).
    - CDF.
  - Possible sub-KPIs are
    - u-plane overhead:
    - c-plane overhead
  - Relates to the amount of resources that have to be used in order to support the novel relaying concepts
- Resource consumption:
  - Were computed as
    - Mean value (across time per data flow)
    - CDF (per data flow)
  - Possible sub-KPIs are
    - Number of PRBs occupied per active data flow on DL and UL.
    - Tx power used by each UE and the RN on the UL.

3.1.2 Link level KPIs

The metrics described in the previous section are intended mainly for system level evaluation. In order to decrease simulation effort, the behaviour of link level is often simulated separately and then modelled for system level evaluations. For the link level simulations different KPIs have to be defined. A widely used list of common criteria was derived within the WINNER II project to compare simulation results:

- Bit error rate / Frame error rate
  - RawBER: Bit Error Rate. For raw performance after the demodulation stage.
  - BER: Bit Error Rate at the output of the channel coding decoder.
  - CWER: Code Word Error Rate. At the output of the channel coding decoder
  - BLER: Block Error Rate. For intermediate decoding of HARQ blocs. It should anyhow be specified especially in case of incremental redundancy cases.
  - FER: Frame Error Rate. The frame represents the information block protected by cyclic redundancy check (CRC) at the radio link control (RLC) layer. It could be a code word; in that case it is equivalent to CWER.
  - IPER: IP Packet Error Rate. The error probability of an entire IP packet.
- User throughput.
- Delay

3.1.3 Field trials KPIs

Various KPIs stated in previous sections, in particular those connected to fairness aspects, are difficult to measure in field trials due to the limited number of UEs/eNBs involved in a measurement campaign. Hence, it appears suitable to define specific field trial KPIs which can then be mapped onto the system level KPIs defined before (e.g. through improved system level simulation[48]):

- BLER / BLER improvements due to the usage of ARTIST4G techniques
- SINR / SINR improvements due to the usage of ARTIST4G techniques
- Throughput / throughput improvements due to the usage of ARTIST4G techniques

3.1.4 Misalignments and issues

In this section, possible problems, issues or misalignments concerning the KPIs proposed in the previous state of the art section are examined. Among those considered are:

- Lack of or inadequate KPIs in order to assess whether the system requirements are fulfilled.
- Lack of KPIs to assess the user Quality of Experience (QoE).
- Lack of KPIs for the assessment of new performance parameters (e.g., energy efficiency).

In the context of the ARTIST4G[49] project, new and refined KPIs have been proposed:

- Single User Performance Metrics

  Single user performance metrics are the most basic ones used to characterize the network. They may be defined for single cell and multi cell and provide, by means of the link budget, an estimation of the cell range and the supported bit rate for a single user. In the single cell evaluation, the link budget provides the noise limited range and bit rate for the system, whilst in the multi-cell evaluation, the performance indicators correspond to the interference limited case. The main issue with these KPIs is that cell range/coverage area are determined based on link budget inputs corresponding to data rates, cell-area reliability etc., and no ITU requirements are specified for these link budget inputs. So there is a degree of uncertainty that may lead to non-comparable results. For example, the shadowing fade margin in the link budget is determined as a function of the cell-edge coverage reliability and the standard deviation of the log-normal shadow fading (including penetration losses if applicable). The cell-edge coverage reliability is determined for the given area coverage reliability as a function of the shadow fading standard deviation and the path-loss exponent obtained from the path-loss model, and it can be determined using simulations or using traditional numerical methods. However, for this parameter, there are not agreed values for the standard deviation of the log-normal shadow fading nor for the path-loss exponent to be used in different environments.

- Capacity related KPIs

Some of the most important KPIs defined in the previous section are related to the capacity estimations associated with the implementation of different techniques. One important issue concerning capacity related KPIs is the possible misalignment between the estimated KPI and the perceived QoE by the user. This is an area that has been addressed by both NGMN and 3GPP in order to provide more meaningful KPIs, especially for bursty traffic conditions, as those indicated in the previous sections. However, there may be different additional problems:

  - Distortions due to TCP flow control mechanisms, like slow-start. Reduced latency may have an impact on window sizes and other parameters.
  - Latency due to signaling procedures when changing of radio resource control (RRC) state. The delay may have a significant impact on the perceived bit rate by the user when a new connection should be established if the volume of data to be sent is small and the bit rate supported is large.

Another aspect that should be taken into account is the support of heterogeneous deployment environments, with macro, micro and femto cells, alongside with advanced relays. These KPIs are being proposed in the context of the project.

- Mobility related KPIs

Mobility KPIs are usually related to the rate handovers fail or succeed, as well as the interruption time due to the completion of the process and the probability of losing data. They are much more significant for real time services, like voice and some video services. Mobility KPIs are difficult to define in a way that reflects QoE estimation, as the latter will depend on different factors like the mobility degree of the user, the characteristics of the network that provides coverage (e.g., hierarchical networks with macro/micro/femto cells), etc. For example, a handover failure rate may provide an acceptable or unacceptable QoE depending on the characteristics of the network. Also mobility is one of the aspects that is more difficult to simulate in a realistic way in system level simulations. Other mobility related procedures, like system selection or tracking area update, are also complicated to assess. For example, evaluating tracking area update success rate is complicated by the fact that tracking areas can be reconfigured in order to optimize paging/update signaling trade-off.

- Performance uniformity KPIs

It is becoming more and more important to improve the performance of users that are in worse propagation and interference conditions, providing a more uniform experience over the whole coverage area. Different possibilities are available: ratio between the maximum bit rate supported and cell edge bit rate, ratio between cell edge bit rate with and without load, percentage of coverage points that exceed a given bit rate threshold, etc. In ARTIST 4G, the use of the Jain Index was proposed for the characterization of the performance uniformity (variability is the term used for characterizing this performance metric).

In real networks, evaluating the performance uniformity would require to distinguish between those cell edge users that are limited (in terms of performance) by coverage and those that are limited by interference. The latter can be improved by means of interference avoidance/exploitation innovations, whilst the former would require mechanisms to improve their sensitivity (e.g., improving the SINR).

- Energy saving KPIs

Technical improvements, reflected in better KPIs, should not come at the expense of excessive energy consumption either by the UE or by the network. In this sense, it would be interesting to rank the proposed solutions in terms of their energy requirements. This is an area that has not been addressed yet. It remains an open issue whether significant results can be obtained from system level simulations for such KPIs.

- SON related KPIs

The standardized set of capabilities known as Self-Organizing Networks (SON) will significantly increase the level of automation in operations and maintenance and decrease the associated OPEX. SON is defined as a set of use cases that cover the entire network lifecycle (planning, deployment, operations, and optimization) and it is being designed to be a multi-vendor solution, with standard interfaces utilized at key points to allow inter-operability between equipment vendors. Some SON algorithms are not standardized in order to allow for differentiation and competition between the vendors infrastructure.

In principle, it could be possible to use system level simulations in order to assess the effectiveness of some SON procedures, especially those intended to improve spectral efficiency and capacity by changing the network configuration. However, in order to obtain relevant performance metrics it should be taken into account that the temporal dynamics of SON are not the same ones as used in system level simulations for the evaluation of, e.g., radio resource management (RRM) procedures.

- Complexity related KPIs

The evaluation of the technical innovations that are proposed should not be limited to the performance they provide, but also to the complexity they introduce. Complexity in this context is understood as a compendium of different factors, like the processing capabilities required for supporting a given innovation by both the network and the UE, the additional control and signaling capabilities to be provided, or any other requirements in terms of infrastructure deployment. Complexity thus becomes a metric of the technical feasibility of an innovation.

Complexity KPIs are difficult to provide until the innovation analyzed is mature enough to design a possible implementation; however some qualitative assessment may be provided, for example, comparing with a baseline system.

- Cost related KPIs

The feasibility of any technical innovation to be incorporated in the standards will depend on the economic viability of its implementation in real networks. In this sense, it would be desirable to introduce some metrics that help to relate the introduction of new features with their associated cost increase (or decrease). Obviously it is practically impossible to perform such evaluation in absolute terms, but it could be possible to provide estimations of relative cost with respect to a baseline configuration.

Obviously, cost and complexity are quite intertwined, as a higher complexity usually implies a higher equipment cost, although also a lower cost per bit (due to higher efficiency).

Considering that interference management is one of the key issues addressed in SHARING, in the majority of the studied cases, the following parameters need to be mentioned:

- The interference power: The average total power of the interferences disturbing that User.
- The interference load: the average number of simultaneous interferers over all resource elements scheduled for that user.
- The interference diversity: the total (cumulative) number of different interferers that have been scheduled on all the resource elements of this user.
- The interference intelligibility: for instance, the average of the difference between the modulation orders of the signal intended to the user and the interfering signals. If the intelligibility is positive, it means that most of the interfering signals are easily detectable, whereas a negative intelligibility indicates that most interfering signals are barely detectable.

These parameters are calculated on resource elements assigned to users. They help characterize the interference environment in which the proposed algorithms are tested.

Note: in the above definitions an interferer is to be understood as the signal intended to an interfering user. Thus the number of interferers is the number of interfering streams, and not the number of interfering base stations. This last set of interference parameters, when associated with corresponding sets of ranges, will form a set of interference scenarios. This can be done when first results of the projects provide the first values for these parameters.

3.2 Selection of KPIs for SHARING

After a thorough review of the proposed scenarios and the expected results, we anticipate that the relevant KPIs the SHARING project take into account the following aspects:

- User traffic (multiple services, service usage, user spatial 3D distribution, time variability).
- Requirements and solutions for a realistic channel modeling, considering heterogeneous cell configurations, multiple frequencies and frequency bands, multi-antenna systems
- HetNet deployment scenarios
- The ratio of the cell-average over the cell-edge spectrum efficiency normalized to the same number of users (Jain index)

The table presented below lists all the scenarios foreseen within the SHARING project and for each of these scenarios, a list of KPIs involved is provided.

Table 1: Summary of scenarios, tasks, partners and KPIs involved

Scenario Title	Task	Partner	KPIs involved
Joint processing CoMP algorithm, combined with interference cancellation at the receiver.	3.1	CEA	Sum rate, Bit Error Rate, Avg. cell throughput
Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks	3.1	FT	Block Call Rate, Cell Loads, File Transfer Time, Throughput, Capacity.
Secure communication with imperfect CSIT	3.1	SUP	Capacity, sum rate
Multipoint Coordination Schemes for LTE-Advanced Networks	3.1	FT	Avg. cell throughput
Joint processing CoMP with limited backhaul and spatial CSIT allocation design	3.1	EUR	Sum rate and/or Degrees of freedom
Interference reduction in LTE through link level processing	3.1/3.2	TCS & SEQ	Bit Error Rate
Broadcast Channel Feedback in Cooperated Multiple Antenna Systems	3.1	FT & EUR	Sum Rate
Joint interference and location prediction	3.3-1	CEA	Interference estimation
Antenna Design: small antenna for femto-cell, compatible with 4G systems bandwidths	3.3-2	CEA & TTI	Radiation pattern.
Interference alignment for large dense network	3.3	EUR	Sum rate OR Degrees of freedom
Flexible interference management schemes for downlink communications	3.3	SUP	Outage, prob of errors, average cell throughput
Relay-aided interference mitigation	3.3	SUP	Capacity region
Carrier aggregation using reconfigurable RF front-ends	3.4	TTI	Cell throughput, cell edge throughput
LTE-A multi-layer network in urban/suburban environments	3.1, 3.2, 3.3	SIRADEL	Service coverage, spectral efficiency, throughput, energy efficiency, …

LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul	4.1	SIRADEL	Service coverage, spectral efficiency, throughput, energy efficiency, …
Performance and energy efficiency evaluation in LTE Heterogeneous Networks	4.1	FT	Average cell throughput and cell-edge (5% percentile)
Mobility load balancing (MLB) in LTE macro cell networks	4.1	FT	Block Call Rate, Drop Call Rate, Load, File Transfer Time, Cell Edge Throughput, Cell Center Throughput
Load Balancing (LB) via transmit power optimization in LTE macro cell	4.1	FT	Block Call Rate, Load, File Transfer Time
HetNet mobility	4.1	ERICSSON	System coverage, System performance, average throughput, Handover failure rate
Macro densification for system capacity/performance	4.1	ERICSSON	System coverage, System capacity, user performance, User drop rate, Noise Rise level
Deployment optimization of Heterogeneous networks in urban/suburban environments	4.1	ERICSSON	System coverage, System capacity, user performance, User drop rate, Noise Rise level
Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks	4.1	FT	Block Call Rate, Cell Edge Throughput, Cell Center Throughput, Load, File Transfer Time for both Target and Observational cells
Dynamic UL/DL duplexing for TDD enabled small cells	4.1	UOULU	Average throughput per user - DL and UL packet throughputs
Theoretical Performance analysis of Heterogeneous Cellular Networks	4.1	SUP	Coverage probability, area spectral efficiency (throughput), average spatial rate
Asymptotic Performance of Hetnets under dynamic traffic	4.1	SUP	Queue stability, Avg. cell throughput
Conversion block	4.1 & 4.2	TTI & ASYSOL	Overhead and delay introduced by the adaptation layer
Seamless Offloading in Heterogeneous Wireless Networks	4.2	AVEA	Client SNR (dB), PSNR (dB), Data received (Kbps), Packet Loss (%), Throughput (Kbps), MOS Value (Mean Opinion Score)
Enhanced InterCell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets	4.2	FT	Block Call Rate, Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Antenna tilt optimization for interference management in LTE-A HetNets	4.2	FT	Block Call Rate, Pico and Macro Cell Edge Throughput, Cell Edge SINR, Pico and Macro Cell Center Throughput, Cell Center SINR
LTE-WiFi offloading	4.2	UOULU	Average throughput per user (-> worst 5^{th} percentile of users -> coverage), Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity)

Dynamic Cell ON/OFF power saving	4.3	TTI	Avg. cell throughput, %savings, μJ/bit (if power models available)
Multi-RAT Heterogeneous networks in urban/suburban environments	4.2, 4.3, 4.4	SIRADEL	Service coverage, spectral efficiency, throughput, energy efficiency, …
ON/OFF power saving in campus of small cells	4.3	MERCE	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Power saving through sum power optimization in HetNet deployment	4.3	MERCE	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
HetNet energy saving via eNodeB sleep mode/cell switch-off	4.3	ERICSSON	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity) Total network power consumption (per hour) kW/km2 Daily energy consumption (accumulated over 24 hours)
Opportunistic ON/OFF switching for small cells	4.3	UOULU	Average throughput per user (-> worst 5th percentile of users -> coverage) Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity), Total network power consumption (per hour) kW/km2, Daily energy consumption (accumulated over 24 hours)
Energy efficiency strategies over different power levels in the power amplifier	4.3	TTI	Energy efficiency, throughput, average output power
Multiflow carrier aggregation	4.4	UOULU	Average throughput per user (-> worst 5th percentile of users -> coverage), Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity), Total network power consumption (per hour) kW/km2, Daily energy consumption (accumulated over 24 hours)
Backhaul offloading via Opportunistic caching	4.4	UOULU	Average throughput per user (-> worst 5th percentile of users -> coverage), Offered area traffic or served area traffic (Mbps/km2, GB/h/km2 -> capacity), Average backhaul load saving
Coordinated carrier aggregation in campus of femto base stations	4.4	MERCE	Cell Edge Throughput, Cell Edge SINR, Cell Center Throughput, Cell Center SINR
Distributed RRM strategies	4.4	SUP	Outage prob, Avg. cell throughput
Joint channel and Network coding for advanced networks	5.1	CEA	Bit Error Rate

Clustered wireless mesh networks based on LTE	5.1	EUR & TCS	For simulation: Packet Error Rate, Avg. cell/user throughput, Avg. user delay, Avg. fairness index, Min throughput, Max delay, Max drop rate For demonstration: Achievable throughput/delay/BLER on relayed CH-CH link, end-to-end throughput/delay/BLER (core network to user)
LTE-Advanced collaborative relaying	5.1	EUR	Achievable throughput on relayed eNB-UE link, end-to-end throughput (core network to user)
Path loss model for relay scenario	5.1	FT	Path loss and theoretical throughput
D2D Unicast communications	5.2	NTUK	Cell throughput, cell edge throughput
D2D broadcast communications	5.2	EUR	- Aggregated throughput - Successful packet delivery rate - Transmission range - Fairness - Delay
D2D communications for overloaded networks	5.2	FT	Avg. cell throughput
Antenna Smart Grid Solutions For Outdoor DAS	6.2	ECE	Capacity and topology comparison
Extension of Performance Evolution for Femto -> Small Cells	6.2	ECE	Smart phones and Smart phone api's
Positioning in Heterogeneous converged Networks	6.2	MAGISTER	Primary KPIs: Cumulative distributions of positioning error over the area of interest, 68%-ile and 95%-ile prediction accuracies over the area of interest, Prediction accuracy vs. confidence in a particular location.

4 Definition of the evaluation methodology

Based on the defined set of requirements, the objective will be to define the evaluation methodology for all the research directions that will be investigated in the project. This definition incorporates channel models, deployments scenarios and simulation tools. Based on these metrics, the project objectives will be quantified for each specific scenario in order to enable the evaluation of the project progress.

On many research topics, performance evaluation metrics and evaluation methodologies are well established based on the results from standardization bodies (3GPP, NGMN, ITU, IEEE) and previous research projects (WINNER[50], EASY-C[51]). In these cases, to maximize the impact of the project and minimize unnecessary efforts, the project only focuses on a reduced number of deployment scenarios and parameters selected from the existing methodologies. Working on such a common reduced set of deployment scenarios will guarantee that different partners and work packages in the project obtain simulation results whose trends can be compared. On the contrary, for topics that have not been deeply investigated in the past, WP2 will aim at establishing a consensus in the industry and scientific community on simple and representative metrics and evaluation methodologies. Multi radio access technologies networks with LTE and WiFi are one of the topics that will require such contributions.

In the following table, the different evaluation methodologies proposed for each scenarios ranging from simulation at different levels (MAC, Link, flow and system), analysis of circuits, relying on theory and statistics are synthesized.

The most frequently proposed evaluation methodology is the simulation at the system level with multi-cell configurations. Simulation at the link level is also proposed, less frequently and MAC level simulation is proposed in two scenarios only.

More extensively, evaluation methodologies proposed are:

- System level simulation
- Link level simulations
- MAC level simulations
- Circuit level analysis
- Experiments with OpenAirInterface
- Use of Cross-layer models based on queuing theory.
- Coverage-based analysis
- Software simulation
- Flow level simulations
- Analytical/Theoretical
- SON techniques

Table 2: Summary of evaluation methodology for each scenario

Scenario Title	Task	Partner	Evaluation methodology
CoMP algorithm, combined with interference cancellation at the receiver.	3.1	CEA	System level simulations
Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks	3.1	FT	Cross-layer models based on queuing theory and system-level simulations.
Multipoint Coordination Schemes for LTE-Advanced Networks	3.1	FT	System level simulations
Secure communication with imperfect CSIT	3.1	SUP	Analytical analysis.
Broadcast Channel Feedback in Cooperated Multiple Antenna Systems	3.1	FT & EUR	Simulations and analytical analysis
Interference reduction in LTE through link level processing	3.2	TCS & SEQ	Analytical and Link level simulations
Joint interference and location prediction	3.3	CEA	System level
Antenna Design: small antenna for femto-cell, compatible with 4G systems bandwidths	3.4	CEA & TTI	Measurements in anechoic chamber
Interference alignment for large dense network	3.3	EUR	Analytical and simulation (MATLAB)
Flexible interference management schemes for downlink communications	3.3	SUP	Analytical and link-to-system level evaluation
Relay-aided interference mitigation	3.3	SUP	Analytical/theoretical
Carrier aggregation using reconfigurable RF front-ends	3.4	TTI	System level analysis
LTE-A multi-layer network in urban/suburban environments	3.1-3.3	SIRADEL	Coverage-based analysis + System-level simulations
LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul	4.1	SIRADEL	Coverage-based analysis + System-level simulations
Performance and energy efficiency evaluation in LTE Heterogeneous Networks	4.1	FT	System level simulations
Mobility load balancing	4.1	FT	Dynamic multi-cell system level simulation
Load Balancing via Transmit Power Optimization in LTE macro cells	4.1	FT	Flow level simulations based on queuing theory
HetNet mobility	4.1	ERICSSON	dynamic multi-cell system level simulations
Macro densification for system capacity/performance	4.1	ERICSSON	Dynamic multi-cell system level simulations

Deployment optimization of Heterogeneous networks in urban/suburban environments	4.1	ERICSSON	multi-cell system level simulations
Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks	4.1	FT	System level simulations
Joint processing CoMP with limited backhaul and spatial CSIT allocation design	3.1	EUR	Analytical and simulation (MATLAB)
Dynamic UL/DL duplexing for TDD enabled small cells	4.1	UOULU	Analytical and Simulations (MATLAB)
Theoretical Performance analysis of Heterogeneous Cellular Networks	4.1	SUP	Analytical/Theoretical
Asymptotic Performance of Hetnets under dynamic traffic	4.1-2	SUP	Analytical/theoretical
Conversion block	4.1 & 4.2	TTI & ASYSOL	Software simulation
Seamless Offloading in Heterogeneous Wireless Networks	4.2	AVEA	Analytical AND System level simulations
Enhanced InterCell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets	4.2	FT	System level simulations
Antenna tilt optimization for interference management in LTE-A HetNets	4.2	FT	System level simulations
LTE-WiFi offloading	4.2	UOULU	System level simulations
Antenna tilt optimization for interference management in LTE-A HetNets	4.2	FT	System level simulations
Dynamic Cell ON/OFF power saving	4.3	TTI	SON techniques for finding the compensation small cells in the campus of the base stations.
Multi-RAT Heterogeneous networks in urban/suburban environments	4.2-4.4	SIRADEL	Coverage-based analysis + System-level simulations
HetNet energy saving via eNodeB sleep mode/cell switch-off	4.3	ERICSSON	multi-cell system level simulations
Opportunistic ON/OFF switching for small cells	4.3	UOULU	Analytical and simulation (MATLAB)
ON/OFF power saving in campus of small cells	4.3	MERCE	System level simulations
Energy efficiency strategies over different power levels in the power amplifier	4.3	TTI	Circuit level analysis
Power saving through sum power optimization in HetNet deployment	4.3	MERCE	System level simulations
Multiflow carrier aggregation	4.4	UOULU	System level simulations
Backhaul offloading via Opportunistic caching	4.4	UOULU	Analytical using synthetic and possibly real traces.

Distributed RRM strategies	4.4	SUP	Analytical
Coordinated carrier aggregation in campus of femto base stations	4.4	MER	System level simulations
Joint channel and Network coding for advanced networks	5.1	CEA	Link level
Clustered wireless mesh networks based on LTE	5.1	EUR & TCS	Link level simulations MAC level simulations Experiments with OpenAirInterface
LTE-Advanced collaborative relaying	5.1	EUR	Link level simulations, System level simulations, Experiments with OpenAirInterface
Path loss model for relay scenario	5.1	FT	Measurement campaign and Shannon capacity
D2D broadcast communications	5.2	EUR	Analytic MAC level simulation/emulation
D2D Unicast communications	5.2	NTUK	System level analysis
D2D communications for overloaded networks	5.2	FT	Link level simulations and single cell System level simulations
Antenna Smart Grid Solutions For Outdoor DAS	6.2	ECE	System level simulations
Extension of Performance Evolution for Femto -> Small Cells	6.2	ECE	Agile method where evaluations are done with few selected use cases. Currently, use cases are the following: • Utilization of smartphones measurements in verification of localizations architecture concepts - Utilization of smart phones for user and network oriented symbiosis e.g. guidance of user based on performance evaluation
Positioning in Heterogeneous converged Networks	6.2	MAGISTER	System level simulations and performance measurements in LTE/WLAN environment.

5 Conclusions

In order to achieve the overall goal of the SHARING project, this deliverable has presented and described the deployment scenarios, the individual partner scenarios within these deployment scenarios, the relevant KPIs (Key Performance Indicators) and involved evaluation methodologies.

The document describes nine deployment scenarios covering LTE and HSPA technologies, macro cells, small cells and HetNets configurations, relay and D2D communications, carrier aggregation and inter-RAT systems, as well as those scenarios where the radio access technology and network type is transparent/generic:

1. Deployment scenario 1: LTE macro cell only
2. Deployment scenario 2: LTE small cell only
3. Deployment scenario 3: LTE HetNet (LTE macro + LTE micro/pico/femto)
4. Deployment scenario 4: Inter-RAT HetNet (LTE + WiFi)
5. Deployment scenario 5: Relays
6. Deployment scenario 6: Device-to-Device (D2D)
7. Deployment scenario 7: Carrier Aggregation (CA)
8. Deployment scenario 8: HSPA
9. Deployment scenario 9: Generic multi-cell/Technology agnostic

These deployment scenarios will allow SHARING to evaluate and compare different deployment strategies for today's and tomorrow's radio access networks in terms of the identified KPIs through the proposed evaluation methodologies. Thus, we will be able to come up with recommendations to the operators on questions on which deployment strategy is expected to bring about how much gain in terms of several important KPIs, under which conditions, what are the drawbacks and architectural impact etc. This will be made possible by the use of the information presented in this deliverable by the other WPs of the project. More precisely, this deliverable will be used to define and refine the research/innovation which will be performed in the other WPs of the project. Besides, technical work in the other work packages of the SHARING project will be made easier by the early definition of scenario characteristics. KPIs and evaluation methodology are also defined at an early stage. KPIs will provide a measure of the success of SHARING.

6 List of Abbreviations, Acronyms, and Definitions

3GPP	Third Generation Partnership Project
AAS	Active Antenna Systems
ABS	Almost Blank Sub-frame
ACTS	Advanced Communications Technologies and Services
ADSL	Asymmetric Digital Subscriber Line
AMC	Adaptive Modulation and Coding
ANR	Agence Nationale de la Recherche
AP	Access Point
ARPU	Average Revenue Per User
ASIC	Application Specific Integrated Circuit
BAN	Body Area Network
BBU	Base Band Unit
BeFEMTO	Broadband evolved FEMTO
BER	Bit Error Rate
BRAN	Broadband Radio Access Network
BS	Base Station
BTS	Base Transceiver Station
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CC	Component Carrier
CCIR	Comité Consultatif International des Radiocommunications
CDF	Cumulative Distribution Function
CDMA	Code Division Multiplexing Access
CEPT	Conférence Européenne des Postes et Télécommunications
CO	Confidential
CoMP	Coordinated Multi-Point
COST	european Cooperation in Science and Technology
CPE	Customer Premise Equipment
C-RAN	Centralized Radio Access Network
CRC	Cyclic Redundancy Check
CRS	Common (or Cell specific) Reference Signal
CS	Coordinated Scheduling
CSG	Closed Subscriber Group
CSI	Channel State Information
CSIT	Channel State Information at Transmitter
CT	Core network and Terminals
CTO	Chief Technical Officer
CTU	Chief Technical Officer
CWC	Centre for Wireless Communications
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DAS	Distributed Antenna System
DeNB	Donor eNodeB
DL	DownLink
DRX	Discontinuous Reception

DSL	Digital Subscriber Loop
DSTL	Defense Science and Technology Laboratory
DTX	Discontinuous Transmission
DVB	Digital Video Broadcasting
E2E	End-to-End
EARTH	Energy Aware Radio and network tecHnologies
EC	European Commission
eICIC	Enhanced Inter-Cell Interference Cancellation
eNB	Evolved NodeB
EPC	Evolved Packet Core
EPON	Ethernet Passive Optical Network
ES	Energy Saving
ETSI	European Telecommunications Standards Institute
EU	European Union
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FPGA	Field Programmable Gate Array
FRN	Fixed Relay Node
FTP	File Transfer Protococl
GA	General Assembly
Gbps	Gigabit per second
Gbyte	Gigabyte
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
GSMA	GSM Alliance
GW	GateWay
HARQ	Hybrid Automatic Repeat reQuest
HDR	Habilitation à Diriger les Recherches
HeNB	Home eNB
HF	High Frequencies
HO	Hand Over
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HW	Hardware
IA	Interference Alignment
IC	Interference Cancellation
ICIC	Inter-Cell Interference Cancellation
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPR	Intellectual Property Rights
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio
JP	Joint Processing
KPI	Key Performance Indicator
L2S	Link-to-System

LAN	Local Area Network
LDPC	Low Density Parity Check
LE	Low Energy
LMMSE	Linear Minimum Mean Squared Error
LPN	Low Power Node
LTE	Long Term Evolution
LTE-A	Long Term Evolution - Advanced
M2M	Machine-to-Machine
MAC	Medium-Access Control
MADM	Multiple Attribute Decision Making algorithm
MBB	Mobile BroadBand
Mbps	Megabit per second
Mbyte	Megabyte
MC	Multi Carrier
MIMO	Multiple Input Multiple Output (MU-MIMO see MU)
MME	Mobility Management Entity
MNO	Mobile Network Operator
MRN	Mobile Relay Node
MS	Mobile Station
MTC	Machine Type Communications
MU	Multi-User
NA	Not Applicable
NAS	Network Access Server
NFC	Near Field Communications
NGMN	Next Generation Mobile Networks
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	OFDM Access
OPEX	Operational Expenditure
OSS	Operations Support System
OSTBC	Orthogonal Space Time Block Code
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PC	Personal Computer
PCC	Primary Component Carrier
PDCP	Packet Data Convergence Protocol
PDF	Probability Density Function
PDR	Packet Delivery Rate
PER	Packet Error Rate
PHY	Physical Layer
PM	Project Manager
PSNR	Peak Signal to Noise Ratio
PU	Public
QMR	Quarterly Management Report
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology

RF	Radio Frequency
RLC	Radio Link Control
RN	Relay Node
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
RTD	Research and Technical Development
RTT	Round Trip Time
RX	Receiver
SC	Single Carrier
SCME	3GPP Spatial Channel Model Extended
SER	Symbol Error Rate
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input Single Output
SME	Small and Medium Entreprise
SMS	Short Message Service
SNR	Signal to Noise Ratio
SON	Self Optimizing/Organizing Network
STBICM	Space-Time Bit Interleaved Coded Modulation
SW	Software
TA	Tracking Area
Tbps	Terabit per second
Tbyte	Terabyte
TC	Test Case
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TD	Time Division
TDD	Time Division Duplex
TM	Task Manager
TR	Technical Requirement
TTI	Transmission Time Interval
TUDR	Typical User Data Rate
TX	Transmitter
UE	User Equipment
UK	United Kingdom
UL	Uplink
UMTS	Universal Mobile Telecommunication System
UT	User Terminal
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Access Network
UWB	Ultra Wide Band
VNI	Visual Networking Index
VoIP	Voice over Internet Protocol
VPL	Vehicle Penetration Loss
WCDMA	Wideband Code Division Multiplexing Access
WiFi / Wi-Fi	Wireless Fidelity
Wi-Fi	Wireless Fidelity

WLAN	Wireless Local Area Network
WP	Work Package
WPL	Work Package Leader

7 Annex: scenarios/partners

This annex indicates which SHARING partner is responsible for each scenario.

Scenario	Name	Partner
Deployment scenario 1: LTE macro cell only		
2.1.1	Mobility Load Balancing (MLB) in LTE macro cell networks	FT
2.1.2	Load Balancing (LB) via transmit power optimization in LTE macro cell networks	FT
2.1.3	Capacity optimization through Active Antenna Systems (AAS) in LTE macro cell networks	FT
2.1.4	Cross-layer performance evaluation of multi-cell cooperative schemes in LTE macro cell networks	FT
2.1.5	Interference reduction in LTE through link level processing	TCS & SEQ
2.1.6	Multipoint Coordination Schemes for LTE-Advanced Networks	FT
2.1.7	Joint Processing CoMP algorithm, combined with interference cancellation at the receiver	CEA
Deployment scenario 2: LTE small cells only		
2.2.1	Dynamic UL/DL Duplexing for TDD-enabled Small Cells	UOULU
2.2.2	ON/OFF power saving in campus of small cells	MERCE
Deployment scenario 3: LTE HetNet (macro + micro/pico/femto)		
2.3.1	Enhanced Inter-Cell Interference Co-ordination (eICIC) for interference management in LTE-A HetNets	FT
2.3.2	Antenna tilt optimization for interference management in LTE-A HetNets	FT
2.3.3	HetNet energy saving via eNodeB sleep mode/cell switch-off	ERICSSON
2.3.4	Dynamic cell ON/OFF power saving	TTI
2.3.5	HetNet mobility	ERICSSON
2.3.6	LTE-A multi-layer network in urban/suburban environments	SIRADEL
2.3.7	LTE-A multi-layer network in urban/suburban environments considering non-ideal backhaul	SIRADEL
2.3.8	Opportunistic ON/OFF Switching for small cells	UOULU
2.3.9	Backhaul offloading via Opportunistic caching	UOULU
2.3.10	Power saving through sum power optimization in HetNet deployments	MERCE
2.3.11	Antenna Smart Grid Solutions For Outdoor DAS	ECE
2.3.12	Joint interference and location prediction	CEA
2.3.13	Performance and energy efficiency evaluation in LTE Heterogeneous Networks	FT
Deployment scenario 4: Inter-RAT HetNet (LTE + WiFi)		
2.4.1	Multi-RAT Heterogeneous networks in urban/suburban environments	SIR
2.4.2	LTE-WiFi Offloading	UOULU
2.4.3	Seamless Offloading in Heterogeneous Wireless Networks	AVEA
2.4.4	Positioning in Heterogeneous Converged Networks	MAGISTER
Deployment scenario 5: Relays		
2.5.1	LTE-Advanced collaborative relaying	EUR
2.5.2	Clustered wireless mesh networks based on LTE	TCS & EUR
2.5.3	Joint channel and Network coding for advanced networks	CEA
2.5.4	Path loss model for relay scenario	FT
Deployment scenario 6: Device-to-Device (D2D)		

2.6.1	D2D Unicast communications	NTUK
2.6.2	D2D broadcast communications	EUR
2.6.3	D2D communications for overloaded networks	FT
Deployment scenario 7: Carrier Aggregation (CA)		
2.7.1	Carrier aggregation using reconfigurable RF front-ends	TTI
2.7.2	Antenna Design: small antenna for femto-cell, compatible with 4G systems bandwidths	CEA & TTI
2.7.3	Coordinated carrier aggregation in campus of femto base stations	MERCE
2.7.4	Multi-Flow Carrier Aggregation	UOULU
Deployment scenario 8: HSPA		
2.8.1	Macro densification for system capacity/performance	ERICSSON
2.8.2	Deployment optimization of Heterogeneous networks in urban/suburban environments	ERICSSON
Deployment scenario 9: Generic Deployment/Technology Agnostic		
2.9.1	Conversion block	TTI & ASYSOL
2.9.2	Energy efficiency strategies over different power levels in the power amplifier	TTI
2.9.3	Extension of Performance Evolution for Femto -> Small Cells	ECE
2.9.4	Secure Communication with Imperfect CSIT	SUP
2.9.5	Flexible interference management schemes for downlink communications	SUP
2.9.6	Theoretical Performance Analysis of Heterogeneous Cellular Networks	SUP
2.9.7	Relay-Aided Interference Mitigation	SUP
2.9.8	Asymptotic Performance of HetNets under Dynamic Traffic	SUP
2.9.9	Theoretical analysis for linearity and power efficiency trade-off in transmitters base stations	SUP
2.9.10	Distributed RRM Strategies without information exchange between the transmitters	SUP
2.9.11	Joint processing CoMP with limited backhaul and spatial CSIT allocation design	EUR
2.9.12	Interference alignment for large dense network	EUR
2.9.13	Broadcast Channel Feedback in Cooperated Multiple Antenna Systems	FT & EUR

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