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Abstract:

Research activities in METIS WP4 include several aspects related to the network-level of future wireless communication networks. Thereby, a large variety of scenarios is considered and solutions are proposed to serve the needs envisioned for the year 2020 and beyond.

This document provides vital findings about several trade-offs that need to be leveraged when designing future network-level solutions. In more detail, it elaborates on the following trade-offs:

- Complexity vs. Performance improvement
- Centralized vs. Decentralized
- Long time-scale vs. Short time-scale
- Information Interflow vs. Throughput/Mobility enhancement
- Energy Efficiency vs. Network Coverage and Capacity

Outlining the advantages and disadvantages in each trade-off, this document serves as a guideline for the application of different network-level solutions in different situations and therefore greatly assists in the design of future communication network architectures.

Keywords:

Trade-off, complexity, performance improvement, centralized/decentralized methods, time-scale, information interflow, throughput enhancement, mobility enhancement, energy efficiency, coverage, capacity, multi-RAT network, Ultra Dense Network, D2D, M2M, moving cells, METIS, 5G

Executive Summary

METIS WP4 develops novel network-level concepts for future network technologies of 2020 and beyond. An inherent part of this task is to develop solutions tailored to the different facets of future communication systems. In more detail, solutions in the field of the METIS Horizontal Topics (HTs), specifically in the field of Device-to-Device (D2D), Massive Machine Communication (MMC), Moving Networks (MN), Ultra Dense Network (UDN) and Ultra Reliable Communication (URC) are being developed. Each of these fields has different requirements and the proposed network-level solutions need to be adapted to fulfil these requirements. A crucial part in the design of network-level solutions is to investigate the trade-offs involved and balance the challenges faced according to the application domain (D2D, MMC, MN, UDN, URC). Hence, a thorough trade-off investigation is key to understand the interdependencies between different aspects and to provide suitable solutions to the applications.

This deliverable provides the results of the trade-off investigation conducted in WP4. The interdependencies of several aspects have been investigated and five key trade-offs have been identified:

- Complexity vs. Performance
- Centralized vs Decentralized
- Long-time-scale vs. Short-time-scale
- Information Interflow vs. Throughput/Mobility
- Energy Efficiency vs. Network Capacity and Coverage.

This document outlines the major challenges introduced by the aforementioned trade-offs. The analysis of those trade-offs will help to understand the fundamental obstacles that are to be faced in the design of network-level solutions for future wireless communications networks.

Against this background, the proposed solutions of WP4 are being analysed to relate their performance to the identified trade-offs and to assess their performance in the respective application domain.

In summary, this document provides general guidelines and recommendations for the design of novel network-level concepts. By understanding the fundamental trade-offs it is possible to balance the advantages and disadvantages of a trade-off and to better tailor the proposed solutions to their application domains and therefore, to support the development of the final network-level solutions discussed in WP4.

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List of Abbreviations, Acronyms, and Definitions

3GPP	3rd Generation Partnership Project
5G	5th Generation
ANDSF	Access Network Discovery and Selection Function
BCCH	Broadcast Control CHannel
BRA	Balanced Random Allocation
BS	Base Station
BSI	Base Station Indicator
CAPEX	CApital EXpenditure
CDMA	Code Division Multiple Access
CCI	Co-Channel Interference
CDF	Cumulative Density Function
CH	Cluster Head
CoMP	Coordinated Multi Point
CPA	Cellular Protection Algorithm
CQI	Channel Quality Indicator
CSG	Closed Subscriber Group
CSI	Channel State Indicator
CSIT	CSI at the transmitter
D2D	Device-to-Device
DB	Data-base
DID	Device-Infrastructure-Device
DL	Downlink
E2E	End-to-End
EEP	Exploration/Exploitation Policy
eICIC	enhanced Inter Cell Interference Coordination
eNB	evolved Node B
FDD	Frequency Division Duplex
FP	Finger Print
HARQ	Hybrid Automatic Repeat reQuest
HeNB	Home evolved Node B
HetNet	Heterogeneous Network
HO	HandOver
HT	Horizontal Topic
IBU	Iterative Backhaul Update
ICT	Information and Communication Technology
IIE	Interference Identification Entity
JT	Joint Transmission
KPI	Key Performance Indicator
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
M2M	Machine-to-Machine
MIMO	Multiple-Input Multiple-Output
MLD	Maximum Likelihood Detection
MMC	Massive Machine Communication
MN	Moving Networks
MNO	Mobile Network Operator

MPA	Message Passing Algorithm
MRN	Moving Relay Nodes
MS	Mobile Station
MTC	Machine Type Communication
NN	Nomadic Nodes
OFDM	Orthogonal Frequency Division Multiplexing
OP	Outage Probability
OPEX	OPerational EXpenditure
OPI	Overall Performance Indicator
OTA	Over The Air
PAS	Predictive Adaptive Streaming
PC	Power Control
PCC	Phantom Cell Concept
PCI	Physical Cell ID
PDCCH	Physical Downlink Control Channel
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service
RA	Resource allocation
RACH	Random Access Channel
RAT	Radio Access Technology
RN	Relay Node
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
SCMA	Sparse Code Multiple Access
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise ratio
SP	Service Provider
SRR	Semi-definite Relaxation and Reformulation
SVM	Support Vector Machine
TC	Test Case
TDD	Time Division Duplex
TeC	Technical Component
TTI	Transmission Time Interval
UE	User Equipment
UL	UpLink
UDN	Ultra Dense Network
URC	Ultra Reliable Communications
V2D	Vehicle-to-Device
V2V	Vehicle-to-Vehicle
VUE	Vehicular UE
WP	Work Package
WRB	Wireless Relay Backhaul

1 Introduction

The objective of METIS WP4 is to investigate network-level aspects related to the efficient deployment, operation and optimization of the future wireless communications system, with an emphasis on heterogeneous multi-layer and multi-RAT deployments. To this end, 5G mechanisms for these aspects have been developed and presented in previous deliverables and internal reports ([MET13-D41], [MET13-IR41], [MET13-IR42], and [MET14-IR43]). These mechanisms have been grouped in Technical Components (TeCs), addressing the same or similar problems; each mechanism is considered as an alternative for solving a specific problem and is referred as Technology Component Alternative x (TeC-Ax). The afore-described analysis has been performed in D4.1 accompanied with the benefits from the introduction of each TeC. However, the introduction of the new and more sophisticated schemes comes with the respective costs in signalling, computational capabilities, energy consumption etc. Thus, one of the key outcomes of WP4, apart from the development of the TeCs, is the investigation of fundamental trade-offs in the design of future wireless communications systems and the extraction of the respective recommendations.

As described afore, the objective of the present document is to describe the key considered trade-offs of the future networks and to provide recommendations based on the performed analysis. The trade-offs are related both to the proposed network level solutions (developed in Task 4.1 and Task 4.2) and the corresponding enablers (developed in Task 4.3). By studying the developed TeCs, the identified trade-offs are the:

- **Complexity vs. Performance Improvement**, which refers to the increase in the computational resources requirements for enhanced performance and captures the balance between the higher accuracy of a mechanism that in general leads to higher complexity of the algorithms. The increase in the complexity is linked to the respective increases in wireless network cost, Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).
- **Centralized vs. Decentralized solutions**, which aims at finding a balance between the benefits of centralized and decentralized solutions, as well as the required degree of centralization for achieving the optimum point in the network operation. Centralized solutions exploit their global views and potentially the higher computational capabilities and energy capacities with the expense of the higher communication cost, which affects their scalability. On the contrary, decentralized methods pose no or limited communication cost to the network achieving however suboptimum solutions. This trade-off tries to find the optimum point between centralized and decentralized solutions, considering also the time-limitations of the specific HTs and Test Cases (TCs).
- **Long Time Scale vs. Short Time Scale solutions**, which is related to the network's/system's dynamics; when the dynamics are fast, the time scales shall be short, whereas when the dynamics are slower, longer timescales may be used. The applied time scales are also related to the monitoring and sensing capabilities of the network. Finally, shorter time scales in general are linked to increased signalling which is a further overhead to the network.
- **Information Interflow vs. Throughput/Mobility Enhancement**, which refers to the burden posed to the network by the need for additional information; such information is required by the new sophisticated mechanisms for enhancing either throughput or mobility management. However, the required additional information shall be considered in conjunction with the benefits of the new schemes, for quantifying the benefits from the introduction of the proposed schemes.
- **Energy Efficiency vs. Network Capacity and Coverage**, which refers to the densification approach that is foreseen to be used in future 5G networks, for meeting the capacity and coverage requirements. This trade-off is related to the dynamic

deployment of the network as well as the optimization of the network operation by making the Base Stations (BSs) more energy efficient. The key challenge of this trade-off is related to the assessment of the network needs in real time in terms of both coverage and capacity.

Once the trade-offs are described and analysed, useful observations and recommendations are being provided so as to set the path for the future networks.

To analyse the previously mentioned trade-offs, the rest of this document is organized as follows:

- **Chapter 2** presents the identified pivotal trade-offs. Afterwards, the basic aspects of the trade-offs are analysed focusing on the considered problems. Additionally, the impact of each trade-off having the METIS Key Performance Indicators (KPIs) as point of reference is identified; similar analysis is attempted for the different HTs and the various TCs.
- **Chapter 3** presents the analysis for all the considered trade-offs. More specifically, the links among the TeC, the trade-off and the effect of each TeC to the corresponding trade-off are identified. Afterwards, the most suitable TeCs for presenting the aspects of each trade-off are being detailed on with additional results for highlighting the key points of the trade-off investigation.
- **Chapter 4** concludes the findings of the trade-off investigation and gives guidelines for the future wireless communications systems. Additionally, it sets the path towards the forthcoming deliverables, during the following months of the project.

Finally, the technical details for the individual TeCs (and the respective alternatives) of WP4 as well as relevant simulation results are presented in the Appendix of the document.

2 Network level trade-offs

The network-level of the future wireless communications networks shows some inherent interdependencies which have to be taken into account when designing efficient solutions. This document refers to those interdependencies as **"trade-offs"**. More precise, the *term "trade-off" is used for a fundamental property of a network level mechanism which can have different orientations*. Depending on its orientation one KPI might improve or another.

As stated in the introductory sections, several schemes have already been proposed by the research community to improve the KPIs for 5G cellular systems. However, introducing a potential solution to the network without taking into consideration all aspects may cause some unforeseen problems. This is why it is needed to identify specific trade-offs for a new mechanism.

Following is an *overview* of the most relevant trade-offs which have been identified in WP4. We highlight *basic aspects* of the trade-offs and elaborate on their impact on METIS KPIs, HTs and TCs.

2.1 Complexity vs. Performance Improvement

In the context of the METIS project, a key network level trade-off that has been identified is "Complexity vs. Performance". Thereby, the level of complexity is considered to be a fundamental property of a mechanism which has an effect on a variety of METIS KPIs, where not all of them can be increased at the same time.

The more important aspect of the "Complexity vs. Performance" trade-off is the increase of the computational resource requirements for enhanced performance. Specifically, such a trade-off captures the balance between, the higher accuracy of a mechanism, which in general leads to higher complexity of the algorithms, and the higher computational cost. Additionally, complex and sophisticated solutions may require additional information for making their decisions. This is related to a potential need for enhanced network characterization or additional periodic or sporadic measurements, not considered by the legacy systems. Apart from the often costly information collection, the information processing may pose a large burden in the communication components. Especially for mobile devices, some solutions will not be supported in practice due to the processing power and the energy constraints. Even with the expected improvements in processing capabilities foreseen for the year 2020 and beyond the computational requirements will be infeasible in many applications.

The applicability of a mechanism is also related to its application domain (D2D, MMC, MN, UDN, URC). The specific problem that each mechanism addresses poses extra requirements. For example, in D2D solutions, the decisions shall be fast, and if the UE has to assist the network in these decisions, the requirements from the UEs shall be limited. On the other hand, in MN solutions, the key requirements are related to the reliability and the delay since for example the 5G equipped vehicles are less strictly constrained by processing and energy consumption. Thus, these solutions need to take into consideration the aforementioned trade-off in relation to each application field so as the designed mechanisms will be deployable in real networks.

Finally, it should be highlighted that potential solutions may on the one hand address the METIS goals, while on the other hand fail to meet all TC KPIs (especially those related to CAPEX and OPEX which are related to additions required for the extra computation capability, the energy consumption induced by the calculations etc.).

2.2 Centralized vs. Decentralized

Centralized and decentralized methods have been of research interest for many years. The related field of distributed computing has a long history dating back at least to the middle of the 20th century when consensus algorithms were studied. One reason why the development of distributed/decentralized methods got in the focus of interest is that it involves the exchange of only very limited amount of information bits.

Related to research in wireless communications the application to resource allocation became of special interest. The underlying challenge in the resource allocation problem is how to allocate a limited amount of resources in the system to maximize a utility while fulfilling Quality of Service (QoS) requirements. Thereby, researchers investigated two fundamentally different approaches towards the solution of this problem, namely centralized and decentralized. Hence, this trade-off is concerned with the level of centralization of a proposed mechanism.

Centralized approaches are characterized by a central unit that has a global view over all available resources and QoS requirements, in an extended area. The complete knowledge of the system serves as a basis to derive a resource allocation strategy which maximizes the utility of interest. A crucial part in such approaches is the information gathering and storage. Generally, the required information about the system is scattered in the system and needs to be transferred to the central unit for processing. Often the transfer of huge amount of data to the central entity, scalability and the issue of single point of failure constitute the main disadvantage of centralized methods. The communication load introduced by this information exchange usually consumes a lot of resources that are not available for payload transmission. Hence, excessive information exchange can greatly degrade the system performance. Especially in large-scale networks such behaviour is most notably evident as centralized methods usually scale poorly. Additionally to the increased communication overhead, the central unit might have to wait for all information to arrive until it can start processing the data and thus introducing delay. Despite all these drawbacks, the strength of centralized approaches is that they are able to obtain globally optimal results in many cases.

In contrast to centralized approaches, decentralized methods usually have no central unit that processes data but rather obtain solutions in a distributed fashion. Thereby, a computing node can autonomously execute an algorithm to solve a network problem with using only little or no communication resources for signalling. Such approaches have a significantly reduced communication overhead and thus scale well with increasing network size. Due to the increasing size of problems in today’s setups and the overwhelming amount of data in systems, the decentralized collection, storage and processing of data are highly desired. Unfortunately, in most cases, such decentralized approaches are suboptimal compared with their centralized counterpart in terms of the desired utility.

Although decentralized approaches often do not attain globally optimal solutions within practical time constraints, a local optimum or even a good solution improving the utility is acceptable when yielding low overhead, good scalability and robustness with respect to node failures. Hence, it becomes evident that in many cases it is desired to trade-off optimality in utility with overhead and scalability.

Therefore, this trade-off is of special importance in the application domain of UDN and MMC where networks usually consist of a huge number of nodes. But also in the D2D or Vehicle-to Vehicle (V2V) communication the question of centralized or decentralized plays a crucial role. In network assisted D2D/V2V communication it might be implementable to have a central unit for centralized approaches. But for solutions where no assistance from the network is available it might be difficult to even implement a centralized solution.

2.3 Long Time Scale vs. Short Time Scale

The distinction between short and long time scale is an inherent part of mobile communications. The physical properties of the wireless channel are usually described by small scale and large scale effects. Thereby, the channel changes due to reflection or scattering in short time (~ms) and large scale effects like distance path loss, channel correlation or shadowing are affecting the wireless channel in longer time scale (in the order of minutes).

Communication protocols usually address either small scale effects or large scale effects. In the Long Term Evolution (LTE) standard for example, the user-sub-band assignment is done for a slow time scale whereas link adaptation is performed on a fast time-scale. Similarly, in systems where the communication of BSs is supported by relays or nomadic cells the coordination and configuration of such supporting nodes have a longer time horizon whereas the resource allocation is done on a short time scale.

Thus this trade-off investigates the effect of the time scale on which a mechanism is operating, where the two different extremes are long time scale and short time scale. The trade-off between long and short time scale is closely connected to the dynamics present in the system. When system dynamics, which are to be addressed by some mechanism, are fast the approach designed for it should rather operate on short time scale to capture all the dynamics. Small time scale approaches are resulting in very flexible and adaptive mechanism with potentially high gains. At the same time the good adaptability comes at the cost of the need for better system monitoring and signalling. The fast system dynamics need to be captured and processed on a similar time scale. Contrarily, if the dynamics are slow there is no gain in short time scale and long time scale is more beneficial. Mechanisms with longer time scale are more static. They are likely to require less frequent information exchange but might not achieve the same gains due to the potential overprovisioning.

2.4 Information Interflow vs. throughput/mobility enhancement

As described by the METIS goals, 5G systems will be required to deliver high data rates, for a large number of devices, in conjunction to enhanced mobility support. For delivering higher throughput, massive connectivity and enhanced mobility, the mechanisms to be introduced will require extended information/input. This leads to a key trade-off which is the “Information interflow vs. Throughput/mobility enhancement”. In other words, we are interested in the impact of the amount of information available on the METIS KPIs.

The required information of the innovative 5G mechanisms is in general related to two aspects, namely the UE mobility and the UE-eNB/UE channel state information. The former concerns UE’s context such as the user location, and speed. The exact position of the UE, even though it is considered that it will be available, poses a heavy burden to the network for constant information flow. Thus, alternatives for rough user position identification may be considered for alleviating the problem. On the other hand, the UE positioning information will enable the network to make sophisticated decisions regarding the radio resources to be allocated in a mobile terminal or to mitigate interference problems. Regarding the UE-eNB/UE channel state information it is expected that it will enable the network to optimize its performance in terms of radio resource management (e.g., in interference mitigation cases or resource allocation). Both, the UE mobility data and the UE-eNB/UE channel state information, are expected to benefit significantly the delivered throughput and the mobility support of the future networks.

However, even when the benefit by the introduction of the sophisticated schemes is apparent, the increased signalling will pose a huge burden in the network especially for MTC communications in 5G. The periodicity of the signalling and the details that will be included in the information exchange suggest a critical point for quantifying the benefits from the introduction of the new schemes. Other potential solutions may be considered in future networks related to group based mobility management, for alleviating the information exchange while maximizing the benefits from the introduction of the proposed schemes.

2.5 Energy Consumption vs. Network Capacity and Coverage

The energy consumption of mobile communication has attracted an increasing amount of attention in recent years, not only because of the substantial impact of ICT on the greenhouse gas emission but also because of rising energy costs and therefore increased operational expenditures (OPEX) for operators.

However, there is a fundamental trade-off between energy efficiency and network capacity and coverage on the network level. BSs are the most energy consuming parts of a cellular communication network due to their large number and operational power supplies. Each BS consumes a certain amount of energy when it is active. The increasing user demands call for complete coverage and boosting capacity of mobile communication networks. One possibility to achieve this is to deploy more BSs in the field, which in turn leads to higher energy consumption. Therefore, smart mechanisms become necessary for ensuring coverage, increasing capacity while leading to only moderate energy consumption increase.

There are several directions that researchers are investigating to keep mobile communication networks energy consumption within certain limits.

A huge research body is investigating the opportunities lying in renewable energy sources and autarkic network elements. Such nodes need only little energy from the fixed energy grid and can either obtain the major part from renewable energy sources like wind, solar or biofuel or all of it.

Another research direction tries to exploit redundancies in the network, and is aiming at identifying only the necessary ones to provide the requested capacity and coverage at every time instance. Especially, the spatial and temporal fluctuation in rural and suburban areas observed during daytime and night-time bears a great opportunity to identify redundancies to turn off network elements. The energy consumption can also be reduced by adapting the capabilities of each network element. There is considerable amount of work on adjusting the cell range by power control, when taking into account the interference coupling in the system. To this extent, also relaying techniques as they are implemented in HetNets using micro, pico and femto cells are beneficial towards a better use of energy. The key challenges include the capability of assessing the service requirements and user needs in real time, capturing the dynamics of the system and translating them to accurate capacity demands and corresponding resource assignments.

In addition to architectural approaches, energy efficiency can also be improved by node level solutions. Indeed, there has been great effort to make BSs itself more energy efficient by innovative hardware design and manufacture. Improved power amplifiers and new cooling concepts are just two of the directions taken to reduce the energy consumption of hardware.

3 Technology Components Managing the Trade-offs

METIS WP4 investigates network-level aspects related to the efficient deployment, operation and optimization of the future wireless communications system, with an emphasis on heterogeneous multi-layer and multi-RAT deployments. The active research against the background of the set of METIS HTs led to a broad spectrum of proposed solutions. Each proposed solution is tailored to certain application domains (D2D, MMC, MN, UDN, URC) with the goal to balance the advantages and disadvantages of identified trade-offs. Below it is elaborated on how WP4 TeCs *relate* to the respective trade-offs.
More precise, this section provides viable information about how the developed mechanisms deal with the identified trade-offs. It will also be shown that the trade-offs have to be addressed differently in each application domain. While the presentation of most TeCs will be limited to conceptual elaborations, for each trade-off one exemplary TeC has been selected to show the trade-off analysis in more detail. The specifics of the trade-off analysis for the remaining TeCs are provided in the Appendix.

3.1 Complexity vs. Performance Improvement

Novel network layer mechanisms developed in METIS WP4 are specifically designed to account for complexity requirements of network entities and UEs. Although it is always desired to maximize the performance of a network in terms of throughput, delay or energy consumption, the accompanying increase in complexity has always been considered. Network assisted D2D communication could provide gains with respect to the throughput enhancement, coverage extension, latency reduction, etc. In order to fully exploit these advantages, diverse algorithms for mode selection (MS) and resource allocation (RA) are being developed in this project. These algorithms aim at the optimization of the overall system performance, including the D2D communication and common cellular communication. Since the traffic conditions and radio conditions for both D2D and cellular users are considered, these algorithms make certain demands on computational complexity.

T4.1-TeC3-A1 provides solutions for joint mode selection and resource management, either in a centralized manner, whereby the cellular BS controls MS and RA, or in distributed manner, when the BS and the devices perform MS and RA jointly. The different schemes not only affect the signalling requirements (this topic will be discussed in section 3.4), but also demand additional computational capacity, either in a central entity that connects the BSs, or distributed at a BS or device. Decentralized MS and RA schemes may lead to suboptimal solutions, however, will offer benefits regarding reduction of the signalling request and avoidance of concentrated computational costs.

The complexity problem for D2D resource management is considered in **T4.1-TeC4-A3** as well. This TeC applies a cell partitioning approach with certain resource reservation assignments. It aims at reducing the complexity of interference management. Above all, it allows for the significant reduction of the required channel measurements (and reports) and enables D2D links between fast moving nodes. Moreover, the TeC allows for the efficient implementation of services with strict QoS requirements exploiting information about their characteristics. In the primary application scenario – automotive safety applications – this leads to (semi-)persistent scheduling in a long term.

T4.1-TeC4-A5 designs a resource management scheme, i.e., RA and power control (PC) algorithm, for D2D-based V2V communications. The complexity of the scheme is considered in the sense that, the RA and PC algorithm can be operated either in a centralized and long-term manner, or in a (semi-) distributed and short-term manner. In this way, the overall system performance can be improved with moderate algorithm complexity.

Besides D2D UEs, when further network entities are considered in the interference management scheme, the complexity of the resource management problem will substantially increase. For instance, **T4.1-TeC1-A3** considers the interference sources such as small (micro, pico, femto) cells and D2D devices. The Interference Identification Entity (IIE) should combine the information from several network elements in the vicinity (UEs, (H)eNBs, HeNB aggregator) in order to identify the source of interference. Due to the fact that several network entities are involved, IIE is called to solve a complicated problem. To this end, IIE provides separate identification mechanisms for uplink and downlink communication, addressing misfortunes and peculiarities that each case presents. Thus, accuracy in identifying the possible aggressors is guaranteed, while extra computational overhead is considered.

T4.1-TeC7-A1 interference mitigation scheme is also assumed to have higher computational requirements. The interference mitigation scheme is based on correlated equilibrium and regret-matching learning algorithms, which increases the overall complexity. The additional resource pattern selection mechanism needs additional computational power at BSs. Computation of utilities for each of the considered strategies is required. However, the complexity can be significantly reduced by applying iterative optimization and simplified utility calculation.

A focal point of this TeC is the systematic studies on the exploitation of context information. Context information such as location, user behaviour and service profile are collected, extracted and analysed and then utilised to facilitate the network management. However, the collection and processing of context information require additional signalling and computational cost.

T4.2-TeC9-A2 utilizes the user position and trajectory as context information for the long-term radio resource allocation. Considering centralized/standalone radio resource scheduling for indoor UDN, context-awareness is proposed to overcome the problem of large UL/DL packet delay for users that are predicted to be in outage while moving around the network. The scheme increases the chance of a user to be scheduled as it approaches the outage zone depending on the upcoming traffic. Knowledge of context information requires extra information flow and computations but achieves performance improvement as mentioned.

T4.2-TeC11 exploits the user behavior depending on the location and the time/date in order to improve the cell selection-reselection and handover schemes. The TeC relies on the principle that the users tend to have similar behaviors in specific locations during specific time-periods. The diverse correlated context information about the user behaviors is extracted using data mining techniques, which will take place in the UE in an asynchronous manner. Since this process is executed offline, only minor computational requirements at the UE are expected.

T4.2-TeC14 utilizes the context information such as user profile, service requirements, geo-location information and available battery energy level for a centralized radio resource management (RRM). Comparing with the conventional resource management scheme, the complexity and signaling overhead increases. The more context information is available at BS, the smarter RRM algorithm can be exploited, and the better system performance can be achieved. However, the performance improvement is at the cost of the increased processing complexity for diverse context information.

T4.2-TeC7 applies fuzzy Q-learning based self-optimization schemes to adapt handover parameter settings. The additional complexity results from several aspects: The applied fuzzy Q-learning method involves system state classification, fuzzy inference system processing, and requires several iterations until learning converges. Further, learning speed depends on the number of considered parameters and employed classification scheme.

Since the learning process can be implemented based on look-up tables and arithmetic operations that can be performed using typical multi-purpose processors, only limited network node-specific processing capabilities are required. There is also certain demand on storage size depending on the number of considered parameters and neighbouring network nodes, as well as the KPI update interval. Fig.Figure 3-1 shows the performance improvements by applying different schemes, which have different complexity requirements.

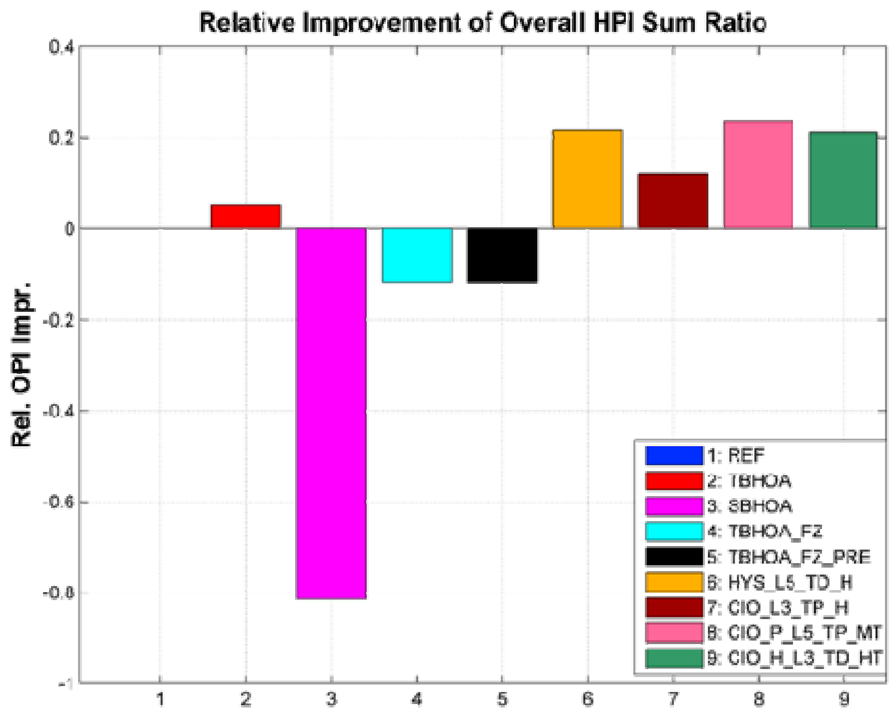


Figure 3-1: Relative improvement of overall HO KPI sum ratio, using 9 learning algorithms; different algorithm results to different effect to the KPIs

In terms of connection drops, reductions of 20-40% can be achieved. In the considered scenario, the number of HO failures was reduced by 80% and regarding ping-pong HOs an improvement of 87.5% was achieved. Overall system performance was improved by 20-22%. For example, scheme 8 exhibits highest complexity and outperforms all other schemes. However, learning process requires second highest number of iterations.

Additional complexity is also induced by new physical layer techniques, which will bring significant improvement to the network level performance. For instance, the sparse code multiple access (SCMA) scheme can be applied to address the issue of massive connectivity with varying traffic load, latency and dynamic signaling overhead (**T4.2-TeC16**). The latency during the contention-based access is largely reduced by the application of multi-layer codebook. It can also provide high throughput for high speed scenarios and improves the robustness of the system to mobility (**T4.2-TeC17**). The complexity of an SCMA receiver is higher than that of a linear receiver. However, due to the sparsity of code words, the complexity of the receiver can be significantly reduced compared to state of the art techniques. Table Table 3-1 shows the complexity analysis of nonlinear MU-SCMA MPA receiver with 2 receive antennas compared with a 2x2 MMSE receiver. The overall complexity of an SCMA nonlinear receiver is about 4 times higher than that of a typical linear MIMO detector.

MPA (4-point SCMA codebook with 6 layers)	Multiplications	Additions	Exponential terms
At a function node (FN) of MPA receiver	265	176	0
At a variable node (VN) of MPA receiver	206	93	0
Euclidian distance	91	144	19
Total	562	413	19
Ratio to MMSE	**3.51**	**3.97**	**2.36**

Table 3-1: Complexity analysis of nonlinear MU-SCMA MPA receiver

Discussion

Throughout the TeCs studied in this document, the performance of the network is expected to improve in various aspects, including supported traffic volume, user throughput, latency, reliability, availability, retainability, energy consumption and cost, which are also identified as KPIs in the METIS project [MET13-D11]. It is shown that certain TeCs obtain the performance gain at the cost of the increase computation complexities, especially the algorithms addressing the interference management problem and the D2D resource management problem. The required computational complexity of these algorithms is strongly impacted by the choice of a centralized or decentralized implementation, which will also be discussed in the following sections.

Some works have been undertaken to achieve the requirement of lower computation complexity. In some TeCs, for instance **T4.2-TeC7**, **T4.2-TeC16** and **T4.2-TeC17**, the increase of the complexity can be limited into certain level without affecting the expected performance gain.

3.2 Centralized vs. Decentralized

METIS WP4 develops several methods and algorithms for D2D communication and UDNs. The design is either centralized or decentralized which bears advantages as well as disadvantages with respect to METIS KPIs such as user throughput or number of supported devices. The following section will elaborate on selected WP4 TeCs that will stress out the strength of using either centralized or decentralized approaches.

T4.1-TeC2 presents a unified resource allocation framework for D2D discovery. Thereby, it considers centralized as well as decentralized solutions. The main idea is a unified framework with the same pre-defined steps to be used for device discovery both under network coverage and out of network coverage. Under network coverage, the eNBs own the discovery resources and manage their allocation in a totally or a semi centralized or fully decentralized way. In the absence of the cellular infrastructure, there is either a clustering approach or a device-centric approach. In the clustering approach, cluster heads (CH) are elected to take over the eNB functionalities. CH nodes continue controlling the resource utilization. Alternatively, the discovery can be performed in a totally autonomous way by a device-centric approach where all devices have the same capabilities and then only best effort type of services are provided. The trade-off between the centralized and decentralized mechanisms is evaluated by means of discovery probability. One of the proposed decentralized schemes shows the clear advantage over other schemes by exploiting the spatial separation of devices for more efficient resource allocation, at the expense of high signalling overhead.

The overall system performance and efficiency of a network-facilitated D2D network is targeted with **T4.1-TeC4-A1**. Two RRM mechanisms are proposed for the studies. A centralized one assuming that both radio resource management and direct or via infrastructure mode selection is performed by a central entity that has the information on the fast fading channel conditions between possible UE-UE and UE-BS links. The second mechanism assumes that such information is available only at the serving BS, while mode and resource selection is done locally by the serving BS based on the channel information reported by UEs connected to this cell. First results show the potential of higher traffic volume served and reduced packet delay for the centralized operating mode compared with the distributed one.

T4.1-TeC6-A1 (coordinated fast uplink and downlink resource allocation in UDN) proposes a centralized RRM mechanism where the macro cell controls the small cells using over the air signalling. Small cells report to the macro buffer and channel state information on the SC-UE link and macro feedbacks scheduling and power constraints to SC that operates in flexible UL/DL TDD mode. The gains of coordination when centralized or decentralized methods are used have been shown by simulations. This technology component aims at exploiting a flexible UL/DL slot configuration in TDD mode that is set by a centralized entity. Flexible resource allocation, if not coordinated between different cells, can lead to overall performance degradation. This degradation can be reduced and performance gains can be obtained when a centralized entity is used.

T4.1-TeC6-A3 investigates a CSI based coordination scheme for macro or small cells with non-coherent JT CoMP. Conventional coherent JT-CoMP systems require CSI at the Transmitter (CSIT), and that the BSs must forward the CSI to the central unit to obtain the precoding weights for interference mitigation. In ultra-dense networks, the signalling data rate might be a significant percentage of user data rate, leading to severe overhead in signalling information. This TeC takes a distributed approach for CSI measurement usage in order to reduce the signalling overhead, leading to a better usage of the air-interface.

T4.1-TeC7-A1 proposes a distributed game theoretic approach to leverage interference leakage to neighboring cells. More precisely, a time-sharing approach is used to mitigate interference using resource auctioning and regret-matching learning. The introduction of interference mitigation based on correlated equilibrium and regret-matching learning increases the overall complexity. The additional resource pattern selection mechanism calls for higher computational power at BSs. When considering the centralized vs. decentralized trade-off, for the proposed decentralized method a periodic exchange of control information is required between the BSs to facilitate the resource use optimization. Two relevant data sets are required for the proposed solution: the information on interference caused to neighboring BSs (this can be updated on long time scale – hundreds of ms) and information on selected resource pattern (shorter time scale – ms/ tens of ms). T4.1-TeC7-A1 aims at the exploitation of proper usage of resources in time, frequency and power domain with the aim at increasing the aggregate throughput in small-cells and, consequently, increasing the aggregate throughput in the network. Although the proposed approach considers optimization of resource usage, similarly to LTE-A eICIC, it is performed in a decentralized manner, with game theoretic approach used to find the optimum solution. Simulation results (illustrated in Figure 3-2 and Figure 3-3) show that the proposed approach (considered in two versions – full and simplified – with reduced number of computations) provides up to 15% increase in aggregate cell throughput and up to 20% increase in small-cell throughput compared to LTE-A eICIC.

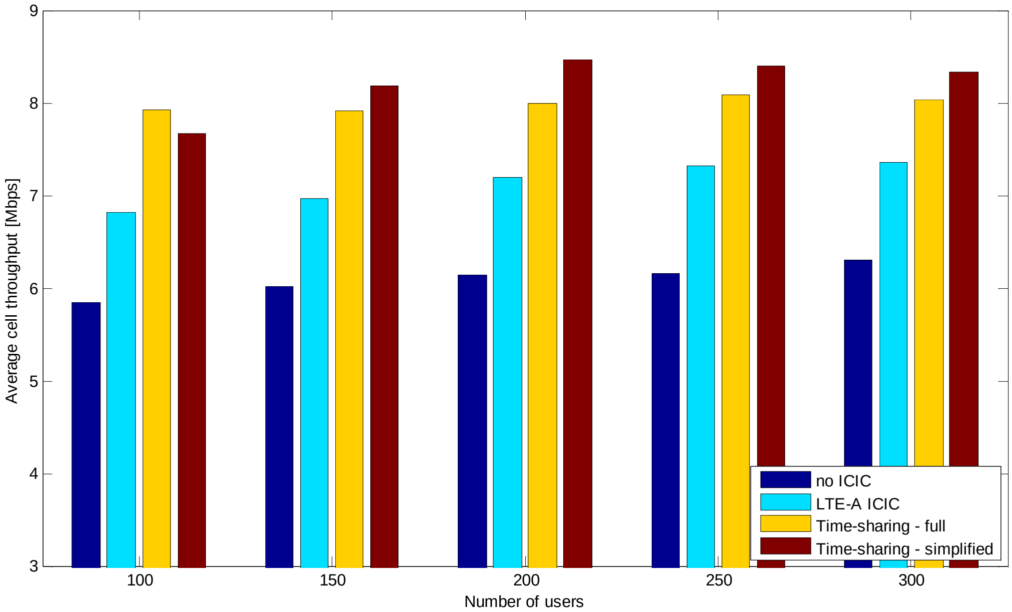


Figure 3-2: Aggregate macro cell throughput. The proposed approach (considered in two versions – full and simplified – with reduced number of computations) provides up to 15% increase in aggregate cell throughput comparing to LTE-A eICIC.

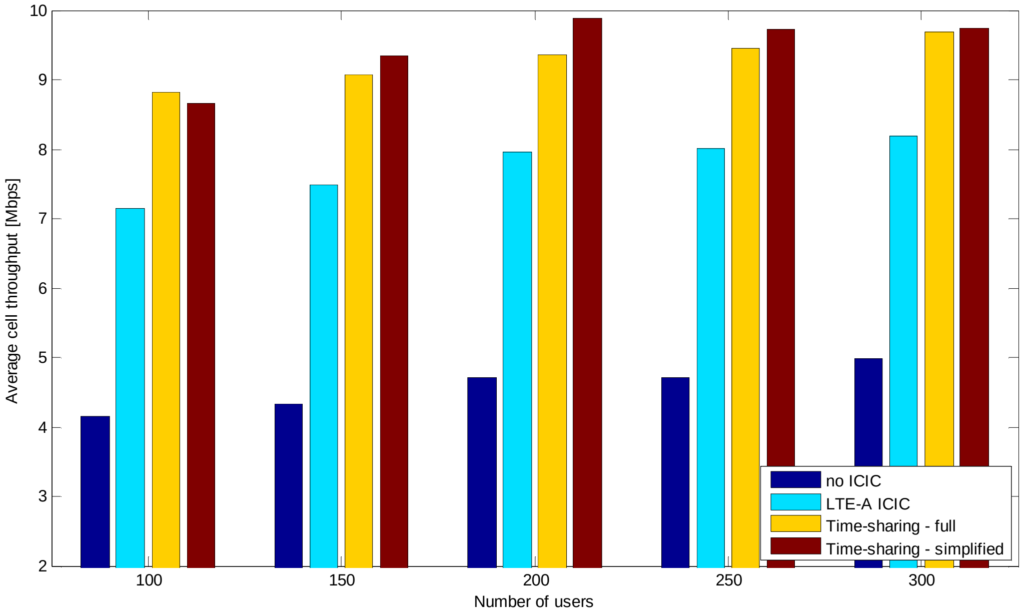


Figure 3-3: Average small cell throughput. The proposed approach (considered in two versions – full and simplified – with reduced number of computations) up to 20% increase in small-cell throughput comparing to LTE-A eICIC.

Discussion

The advantages and disadvantages resulting from the centralized/decentralized trade-off have been analysed for the relevant TeCs of WP4. In the application of device discovery and resource allocation for D2D **T4.1-TeC2** and **T4.1-TeC4-A1** show that the performance in terms of provided traffic volume can only be achieved with the cost of higher signalling.

To avoid a significant increase in the signalling overhead **T4.1-TeC6-A3** proposes a decentralized scheme for CSI based coordination. On the other hand, **T4.1-TeC6-A1** points out the potential improvements in hierarchical UDNs obtained when implementing a central unit that coordinates RRM. Throughput improvements are also possible with decentralized approaches as proposed by **T4.1-TeC7-A1**.

3.3 Long Time Scale vs. Short Time Scale

The time for how long a specific resource assignment or node configuration is valid is a key differentiator in the system performance. Hence, special attention has been paid to the time scale in several WP4 TeCs.

Moving networks typically change fast. In **T4.1-TeC4-A3** the properties of V2D communication (short range, periodicity, …) are exploited in order to enable the integration of automotive services in 5G networks. By applying a cell partitioning approach with certain resource reservation assignments, this TeC aims at reducing the complexity of interference management in a D2D-enabled cellular network over a longer time scale. Thereby, it allows for the significant reduction of the required channel measurements (and reports) and enables D2D links between fast moving nodes. Moreover, this TeC allows for the efficient implementation of services with strict QoS requirements exploiting information about their characteristics. In the primary application scenario – automotive safety applications – this leads to (semi-)persistent scheduling in a long term. Simulations provide strong indications that with the long term approach the performance for D2D can be increased.

An approach to V2V communication is investigated in **T4.1-TeC4-A4**, which is especially interesting for communication on highways. This TeC includes a cluster concept for vehicular safety applications, where the cellular network nodes assist few vehicles or cluster heads (CHs) to take over the control of the direct V2V communications for a group of attached vehicles. The role of the CH is to control the vehicles within its cluster, to handle the cluster joining and leaving requests, and to manage the radio resources on the basis of resource assignment received from the cellular node. The CH periodically updates the network nodes with the cluster description specifying the characteristics of the corresponding cluster such as average position, average velocity and the direction of the cluster members. The performance of such a mechanism is mainly, but not exclusively, driven by the update interval of resource assignment and CH selection. Generally, a shorter update interval prevents the scheme to result in outdated information or inefficient radio resource management at CHs or vehicles in the cluster. On the other hand, the more frequent updates will increase the signaling burden in the system.

T4.1-TeC6-A2 (Out-of-band advanced block scheduling in heterogeneous networks) is mainly applicable in UDN scenarios. Traditional frame usage coordination procedures are time-domain based, employing semi-static patterns of unused subframes as reported through inter-cell interfaces (such as X2). These patterns are however infrequently updated, while air interface traffic can be widely variable in short time scales; in addition, signaling through X2 is prone to significant delay and other impairments. Therefore, radio resource coordination between macro cells and small cells cannot be optimally performed. The proposed technical component uses a coordinated advanced block scheduling for interference avoidance, using out of band (via TDD) signaling for coordinating FDD communication among the small cells and the macro layer, as well as providing a synchronization reference for the small cells. Thereby, much better radio resource coordination is possible due to shorter update circles and shorter delays.

The trade-off between short time scale and long time scale is also evident in the organization of femto cell clusters which is investigated in **T4.1-TeC7-A5**. Operation of this TeC requires femto cells to periodically listen to the macros' beacon signals in order to track synchronization. While doing this, femto cells must switch off their transmitters in order to avoid self-interference, hence deferring downlink traffic with an impact on throughput. The synchronization process should therefore be as quick as possible in order not to impact downlink throughput significantly. However, the quicker the synchronization process, the lower the ability to synchronize in poor signal-to-noise conditions. The minimum time for acquiring synchronization in the proposed TeC is the averaging window length (in ms). Thus there is a trade-off between averaging time and downlink throughput. The resulting self-organized clusters of neighboring femto cells can improve user experienced data rate by firstly allowing the controlled use of otherwise interfering neighbor resources, and secondly enabling advanced inter-cell coordination mechanisms in a distributed way. Figure Figure 3-4 shows the effect of the window size and the beacon's SNR over the 90% synchronization time. Very poor SNR (-10 dB) leads to long time scales even with large window sizes (up to 516 ms), and moderate SNR (-5 dB) can yield very low synchronization times for small buffers (150 ms with 8 subframes buffer). Impact on DL throughput should therefore be carefully studied in very poor SNR conditions. Most realistic deployments yield beacon's SNR values well above 10 dB, thus leading to very good results with minimal window sizes and little impact on DL traffic.

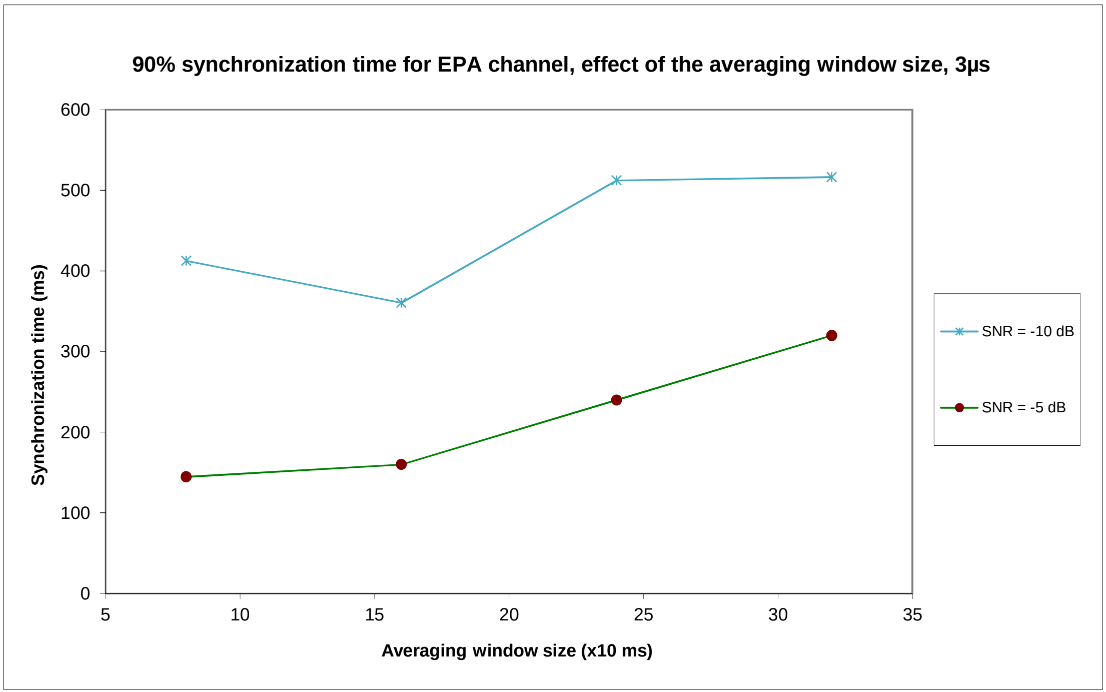


Figure 3-4: 90% synchronization time as a function of the averaging window size for ±3 µs maximum time offset. In low SNR regimes the synchronization time is considerably higher than for moderate SNRs. Furthermore, the averaging window size has a noticeable impact on the synchronization time. The larger the window the longer the synchronization time.

Clustering is identified as a key enabler in UDN for interference management. Thereby, clusters can either be semi statically defined or dynamically adapted. In this context **T4.1-TeC9** proposes dynamic clustering mechanisms. Due to the mobility of users and cells, and to the presence of nomadic cells that may switch on and off, the optimum clustering changes as fast as the network dynamics. Thus it might be not enough to design long-term clusters, which do not adapt to the network changes. This TeC proposes dynamic clustering, valid for mid-term taking into account the SNR of users but not shadowing or fast fading.

In wireless communications systems and especially in UDNs the time-scale for which a scheduling and resource allocation is done directly affects the system performance. In this context WP4 looks into long-term context aware scheduling for ultra-dense networks (**T4.2-TeC9-A2**). Considering centralized/standalone radio resource scheduling for indoor UDN, context-aware functionality is proposed to overcome the problem of large packet delay for users that approaching outage zones, also known as coverage hole within the building. The scheme prioritizes the user scheduling decision on a time-unit bases so that it can send/receive the intended traffic as good as possible before entering the outage zone. In a legacy system for such an indoor scenario with coverage holes, the user would suffer significant delay if scheduling decisions were made regardless of knowledge of future user trajectory. Utilizing the proposed scheme will significantly reduce the packet delay for the user that is approaching the coverage hole: up to 40% by standalone scheduling and up to 50% by centralized scheduling with flexible uplink/downlink partitioning. On the other hand, other users are not affected because no significant degradation is observed on their packet delay.

Discussion

The importance of the right time-scale is most important when the environment is changing. Hence, several WP4 TeCs address RRM for V2V and moving networks where the communication environment constantly changes. **T4.1-TeC4-A3** obtains performance improvements by a long-term pre-assigned cell partitioning for RRM. Another approach is taken in **T4.1-TeC4-A4** where a cluster head performs RRM on shorter time-scales and the update cycle used is shown to affect the performance gains. The update cycles also play a crucial role in the design of HetNet communication schemes (**T4.1-TeC7-A5**) where micro cells support the macro cell communication. Especially in UDN a long term context aware scheduling proofs to be beneficial to avoid large packet delays by **T4.1-TeC9**.

3.4 Information Interflow vs. throughput/mobility enhancement

Most of the interference management schemes require the knowledge of the radio environment, in particular the transmitter-receiver and interferer-receiver, channel state information. For instance, in **T4.1-TeC1-A3** measurements such as RSRP and RSRQ need to be collected at a centralized entity, i.e. Interference Identification Entity (IIE) for the identification of the interferer. Additional information about user device position and location-environment is also required at IIE. This information is acquired from several network elements (UEs, eNBs, HeNB, …) via different interfaces. Thus, this scheme requires additional signalling overhead in air interface (mainly in uplink), X2 interface and backhaul.

T4.3-TeC3-A2 requires signal-to-interference plus-noise ratio (SINR) on the backhaul link for the selection of nomadic nodes (NN). The signalling overhead incurred by the optimal NN selection, due to frequent channel quality information exchange, is higher than the one pertaining to a coarse NN selection.

CSI is relevant for D2D based communications as well. In addition to the conventional CSI between BS and cellular devices, the channel states between D2D devices should also be known. **T4.1-TeC3-A1** provides both centralized and decentralized schemes for mode selection and resource management. Channel state information, resource availability and current load situation are taken into account for the mode selection. For the centralized scheme, these measurements should be available in a central entity, which requires higher signalling cost than the decentralized scheme. However, decentralizing mode selection and resource allocation may lead to suboptimal communication mode selection and resource allocation to the cellular and D2D layers in terms of spectral and energy efficiency.

Instead of actual channel state measurement, location information can be used in D2D mode selection and resource management. Location based mode selection (studied in **T4.1-TeC3-A2**) and resource allocation schemes (studied in **T4.1-TeC4-A2**) avoid the effort of overhead intensive channel measurements and channel state reports, but location information is needed for the pathloss estimation. The amount of signalling overhead introduced by these schemes depends on how the location information is obtained. In the case of using a satellite positioning system the user has to report its position to the central entity. In the case of measurement based positioning, the entities involved in the measurements have to exchange the results of the measurements. Nevertheless, the envisioned increase in signalling is expected to be relatively low in the case of the centralized schemes, and far less than in the case of decentralized approach. This increase in signaling is a price to be paid for increase in cell throughput and number of connected users.

T4.1-TeC4-A3 applies quantized/crude position information (zone index) for the D2D interference management, which further reduce the complexity and signalling overhead. In comparison to the other approaches, this TeC would significantly reduce the signalling overhead in the case of periodic D2D communication. At the same time, it would enable D2D communication between fast moving network nodes. Resource allocation in long term also contributes to the reduction of the overhead. In result, the achieved performance might be sub-optimal in terms of total network capacity, but will, be sufficient for the support of some desired services.

The interference issue between D2D users and small cell users is addressed in **T4.1-TeC15**. In order to avoid or limit the interference to the small cells, D2D UEs need to do measurements of small cells. These would be likely part of normal connected mode operation. Reporting the measurement results would cause a small additional overhead, but that would be small compared with the available capacity gain.

The interference mitigation schemes in **T4.1-TeC7-A1** require the information on interference caused to neighboring BSs (this can be updated on long time scale – hundreds of ms) and information on selected resource pattern (shorter time scale – ms/ tens of ms). The additional signaling due to the information exchange between BSs will be acceptable (only resource pattern index on short time scale; interference information on long time scale). It is expected that the amount of exchanged control information will be lower than that for centralized schemes, such as CoMP.

T4.2-TeC4 schedules UE's delay tolerant heavy traffic activity (e.g. backup, SW update, cloud synchronization etc.), so that it takes place when a UE has a high capacity network connection (for example when UE is offloaded to a small cell). For this approach, minor additional signalling is required for exchanging information of pending non-urgent data, sending wireless connectivity options (small cells in the proximity) and scheduling recommendations.

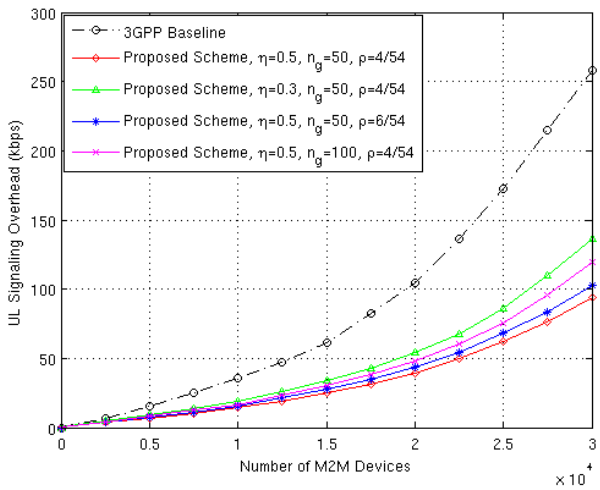
As mentioned in Section 0, the context-aware techniques require not only additional computational cost for the data processing, but also additional signaling overhead for the exchange of relevant context information. For instance, in **T4.2-TeC9-A2**, user trajectory, radio coverage maps and statistics for user mobility, interference and load should be available in a central database. In **T4.2-TeC13**, radio fingerprints of the coverage carrier (e.g. RSRP of neighboring macro cells) should be collected.

T4.2-TeC10 investigates signaling required for trajectory prediction and context awareness through prediction of next cell. Context information, such as user location, velocity, etc., is regularly sampled, e.g. every 300 ms, for deriving position predictions. Further, radio signal information (geometry) is measured periodically with respect to the neighboring BSs. Once the next cell is predicted, a context message needs to be sent to the predicted next cell from serving BS, in order to reserve resources or prepare for context aware RRM. The signaling overhead is increased due to the above factors. The rate of acquisition of context information such as user location, geometry etc. can be relaxed for users travelling at low velocity. Additional context information about mobility of users (e.g. diurnal mobility) and road maps will be beneficial to deduce initial and final positions of the user and better prediction of future positions. The additionally required signalling varies with user velocity, sampling interval and cell radius. At higher velocities and smaller cell sizes, signalling required becomes higher.

T4.2-TeC5-A1 provides a mechanism that takes into account the leveraging parameters such as the mobility of the UE (low, medium, high), the load of the (H)eNB/Wi-Fi AP, as well as the backhaul load of the network and session-related context information (e.g. how sensitive a specific service/session is to network latency) to select the optimal RAT. With regard to signaling, in order for the UE to acquire the essential information for the RAT evaluation (e.g., (H)eNB load), some extra signaling is required, mainly between the IE and the Access Network Discovery and Selection Function (ANDSF) instance that owns this type of information. On the other hand, the mechanism evaluation during the simulations has shown that the overall number of handovers tends to be minimized, resulting in a signaling reduction between the UE and the (H)eNBs/WiFi APs. Hence, the signalling increase due to the information acquisition from the UE is balanced by the minimization of the overall number of handovers realised by the UE resulting from the mobility enhancement.

Context information can be used to group network nodes (user devices or BSs) into concise clusters for better coordination. The clustering procedure is the essential enabler for group-based schemes, such as **T4.1-TeC4-A4**, **T4.1-TeC10** and **T4.2-TeC12**. Different clustering schemes are evaluated and compared in **T4.3-TeC2**. The network nodes with high similarity are grouped in the same cluster. Means of similarity, in mobile networking environments, are e.g. high signal quality from neighboring nodes and close distance among nodes. Thus, the application of clustering mechanisms increases the number of messages that can be exchanged as each cluster only needs to send a single message each time.

T4.2-TeC12 aims to reduce the signaling overhead for MMC traffic and to mitigate the possible congestion in the signaling channel. Hence it has a direct impact on the signaling overhead in the uplink and downlink channel. Depending on the traffic load in the network and the correlation between the signaling messages, the TeC provides different level of improvement in the signaling channel. In order to coordinate the RACH access between different devices, additional cost in the broadcast channel is required. Furthermore, context information utilized to group the devices is necessary. Fig. Figure 3-5 and Figure 3-6 show the performance with respect to the signalling overhead in RACH/PUSCH and BCCH channels caused by the random access process proposed in T4.2-TeC12.



η: Percentage of redundant messages

ng: Group size

ρ: Percentage of RACH resources assigned to the group representatives

Figure 3-5: Reduction of UL signalling overhead by applying coordinated RACH scheme

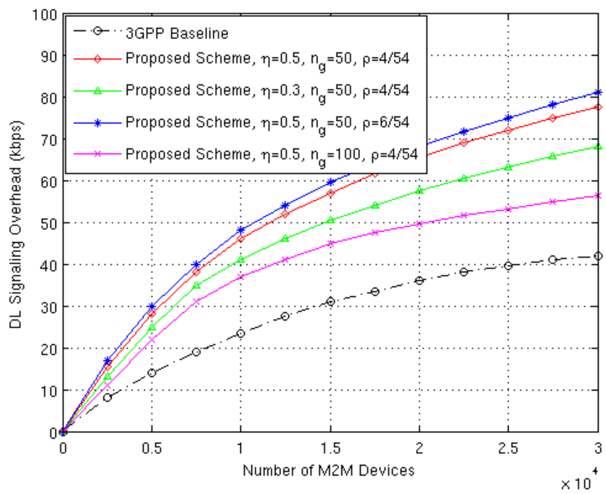


Figure 3-6: Increase of DL signalling overhead applying coordinated RACH scheme

As shown in the simulation plots, the implementation of the proposed mechanism yields significant reduction in the overall signaling overhead as well as the averaged random access delay, especially when the number of deployed M2M devices grows large.

For instance, compared with the 3GPP baseline defined in 3GPP TS 37.868 and in the presence of 30000 simulated M2M devices, the proposed scheme can reduce up to 50% of the uplink signaling overhead. Even though this reduction comes at the cost of additional downlink signaling in the BCCH and PDCCH, the newly introduced DL signaling overhead is small compared with the gains obtained in the UL signaling, thus it still results in a significant reduction in the overall signaling overhead. Besides, the proposed mechanism also improves the network performance by decreasing the averaged random access delay by more than 230 ms.

Discussion

In the above studies, it can be observed that the higher information interflow is mainly caused by the requirement of additional input information, which is used to support the proposed mechanisms. In particular, the extra context information, such as location information, is required in the context-aware schemes. Similarly, in the proposed interference management schemes additional information is required regarding radio environment and interference measurement. In contrast, the proposed mechanisms (e.g. **T4.3-TeC1**, **T4.3-TeC3**, etc.) have less demand on additional control information. That is to say, the increase of signalling overheads is rather in uplink direction than in the downlink direction. Some overhead will also be raised in backhaul links, in links between BSs and between various network entities.

3.5 Energy Efficiency vs. Network Capacity and Coverage

This section presents some important aspects of WP4 TeCs related to the energy efficiency. The energy efficiency has been specifically addressed by WP4 TeCs, and some valuable insights in the trade-off between energy efficiency and network capacity and coverage have been obtained.

In the context of D2D communication it is highly desired to operate in an energy efficient mode due to the limited energy resources of some (possibly battery powered) communication devices. To this regard **TeC 4.1-TeC5** is a key technology component that balances out the spectral efficiency and the energy efficiency. At the same time, it protects the cellular layer from excessive interference. The SINR target and the transmit power levels are adaptively changed by a single parameter to tune towards energy efficiency or spectral efficiency. The results provided in Figure 3-7 show that the TeC introduces significant SINR improvements for D2D communication compared with legacy (LTE) power control mechanisms. Additionally, in many cases it is possible to obtain higher SINR values with a reduced D2D power.

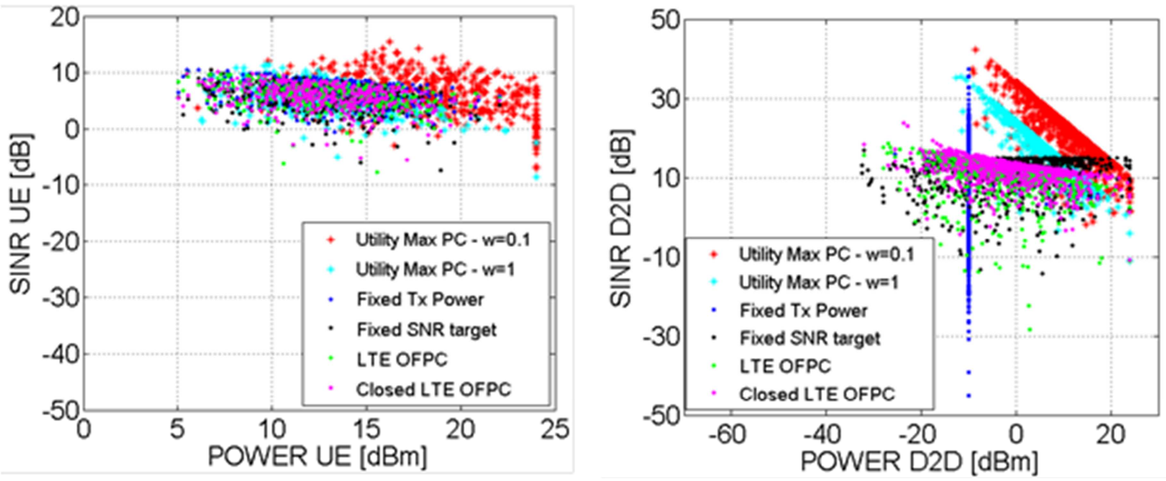


Figure 3-7: Scatter plot of the achieved SINR and invested transmit power levels of cellular users (left) and D2D user (right) in a mixed cellular multi-cell scenario when employing different power control strategies. A distributed utility optimization scheme can improve the SINR performance of both the cellular and D2D layers with similar overall invested power levels as used by legacy schemes.

In heterogeneous networks, where small cells are deployed to increase the capacity provided in a certain area, the energy consumption of the network is the aggregated energy consumption of all active network elements. Using the phantom cell concept, where there is a central entity that is responsible for signalling, it is also possible to operate the network more energy efficiently**. T4.3-TeC5** investigates the potential energy savings in the phantom cell concept where a centralized database helps with the decision of which BS in the data plane should be deactivated. While the considered database-aided scheme helps to reduce the energy consumption of the system by turning off unused small cells, it is subject to some connection setup delays, which can potentially reduce the average achievable user throughput.

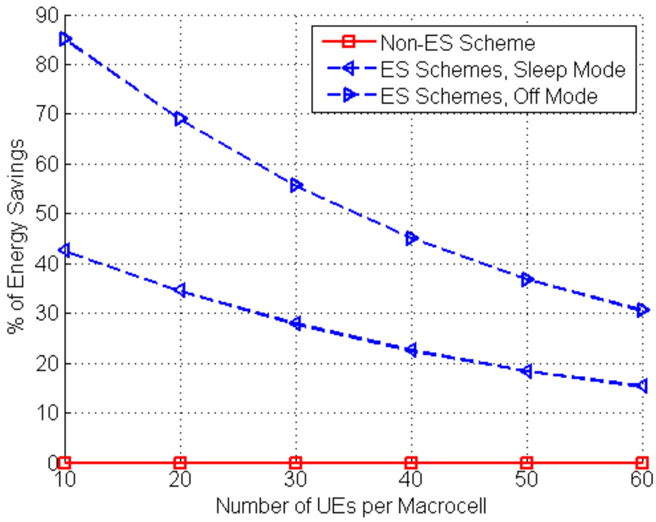


Figure 3-8: Achievable energy savings in the small cell network by the various simulated schemes. Up to 85% energy savings for low network load and up to 30% of energy savings for high network load can be potentially achieved for sleep mode nodes consuming 50% of energy of active nodes.

Simulations results provided in Figure 3-8 show energy savings which can be obtained with this scheme: when unused small cells go into a *sleep* mode, where they consume a non-negligible amount of energy (50% of the energy consumption of an operational small cell), and energy savings obtained when unused small cells are completely turned *off*, in which state they consume only a negligible amount of energy (0% of the energy consumption of an operational small cell). Up to 85% energy savings for low network load, and up to 30% of energy savings for high network load can be potentially achieved.

Another TeC that investigates the optimal set of active network elements is **T4.3-TeC4-A1** (activation and deactivation of nomadic cells). This technology component models the decision of activation and deactivation as an optimization problem where the objective could be energy consumption of the whole network, user battery life, network load, etc. The constraints of the optimizing problem lie in two aspects:

1. UEs and RNs must be connected to the network
2. The available bandwidth at each node must be sufficient to support the minimum rate requirement of the UEs and the forward data rate of the RNs

Certain relaxation techniques are needed to efficiently solve the optimization problem since solutions will lead to more energy efficient network topologies. The gains originate from the overprovision of the network. Hence, the direct trade-off between provided capacity and network energy consumption can be shown.

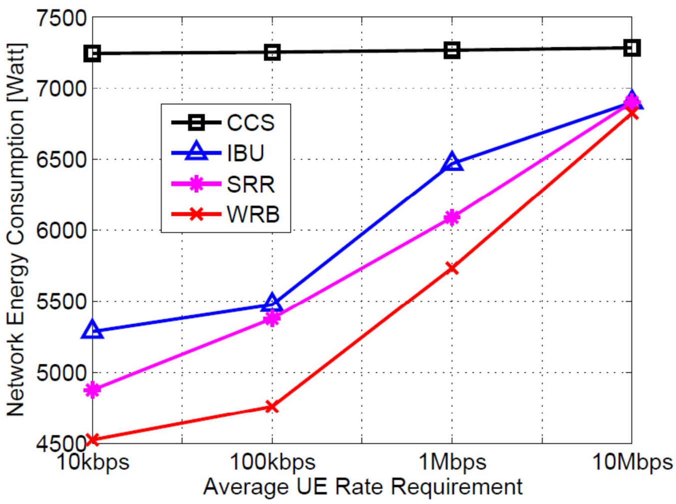


Figure 3-9: Network energy consumption vs average UE rate requirement for different considered algorithms. The network energy consumption can be considerably decreased with the proposed deactivation schemes in low load situations.

T4.3-TeC4-A1 aims at activating BSs and nomadic relays on demand. That is to say, when the traffic load is low, energy saving can be achieved by deactivating sites of BSs or nomadic relays. Two algorithms are proposed, namely, Iterative Backhaul Update (IBU) and Semi-definite Relaxation and Reformulation Techniques (SRR) together with a special case where the relays have fixed backhaul link (WRB), which can be seen as a lower bound of the other two algorithms. Figure 3-9 shows the potential energy reduction under different user rate requirements scenarios. It can be seen from the figure that, in case of low average user rate, significant energy savings can be expected in nomadic relay network.

Also, in the context of small cells there is **T4.2-TeC13**. Configuring a UE with a set of fingerprints (FPs) that correspond to small cell locations on other frequencies allows a UE to limit its inter-frequency measurements (for finding inter-frequency small cells). UE can measure only when it is within or near the coverage of a small cell thus avoiding unnecessary measurements. This decreases the UE's energy consumption. When there are a large number of carriers to search, the search also becomes on average faster because the UE can directly search the correct carrier. Figure Figure 3-10 illustrates the trade-off between power consumption of small cell search (inter-frequency measurements) and fingerprint coverage. This is given for different numbers of FPs per small cell location. Different FP matching ranges have been considered to obtain the different trade-off curves between fingerprint coverage and measurement power saving.

Increasing the number of fingerprints per small cell allows more accurate mapping of small cell coverage and thus a better trade-off between fingerprint coverage and power saving. However, in practice the number of fingerprints is limited due to the signalling overhead from transmitting those to the UE.

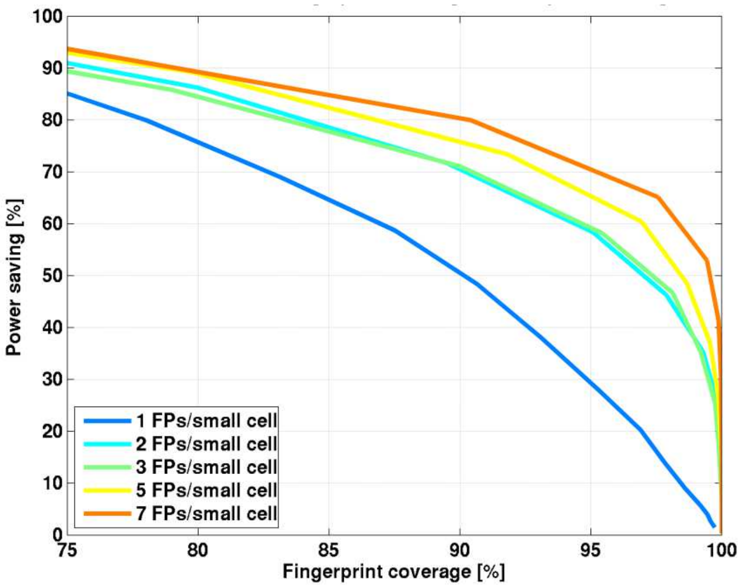


Figure 3-10: Achievable trade-offs between UE power saving (of power consumption due to the inter-frequency measurements) and fingerprint coverage (area of small cell coverage where there is a matching fingerprint) for different number of radio fingerprints per small cell.

Discussion

The TeCs related to the trade-off between energy consumption, coverage and capacity highlight two important aspects. Firstly, it is shown that in HetNet scenarios the provided capacity should be adapted to the actual demand for reduced consumption and energy efficiency. Thereby, the identification of redundant network elements plays a crucial role and is solved by optimization techniques (**T4.3-TeC4-A1**) or database based policies (**T4.3-TeC5**). The second aspect is related to energy efficient communication schemes in D2D scenarios. It has been shown that communication schemes can indeed be operated more energy efficient (decreased transmit power) while maintaining an acceptable performance level (**TeC 4.1-TeC5**). The interdependency of accuracy of fingerprint coverage and energy savings has been illustrated with the help of **T4.2-TeC13**.

4 Conclusion and future work

Deliverable D4.2, entitled "Final report on trade-off investigations" has described and analysed the key trade-offs considered in WP4 METIS 2020. WP4 develops network level solutions related to the efficient deployment, operation and optimization of the future wireless communications system, focusing on heterogeneous multi-layer and multi-RAT deployments, containing the important trade-offs related to the network operation. As also thoroughly described in the body of the document, the identified trade-offs are:

- Complexity vs. Performance Improvement,
- Centralized vs. Decentralized solutions,
- Long Time Scale vs. Short Time Scale solutions,
- Information Interflow vs. throughput/mobility enhancement,
- Energy Efficiency vs. Network Capacity and Coverage.

In this section the trade-off conclusions are provided. Firstly the trade-offs are being wrapped up and then potential directions as well as the linking of the trade-offs are provided.

4.1 Summary of the trade-offs

4.1.1 Complexity vs. Performance Improvement

The complexity vs. performance improvement trade-off refers to the increase in the computational resources' requirements for enhanced performance and captures the balance between the higher accuracy of a mechanism and the introduced higher complexity of the algorithms. In general, increased performance in terms of accuracy is linked to more sophisticated mechanisms that require additional information as well, apart from the additional computational capabilities. Both of the previous aspects (i.e., need for more computational capabilities and additional information) increase the need for hardware as well as communication overhead which has a direct impact on both CAPEX and OPEX.

It should be noted that one of the key outcomes of the performed analysis is that the required accuracy is related to the corresponding scenario (e.g., different levels in accuracy are required for the safety test cases, as URC, and different ones in the UDN test cases). The performed trade-off analysis has been highlighted with two examples; one related to HO optimization and the other one addressing massive connectivity with varying traffic load, latency and dynamic signaling overhead using SCMA. In the former case, the effectiveness of the learning algorithm for HO prediction is linked to the performed iterations (i.e., complexity) in the learning phase, whereas in the latter the SCMA schemes perform better, but with a nonlinear growing of complexity cost.

4.1.2 Centralized vs. Decentralized

The centralized vs. decentralized solutions trade-off aims at finding a balance between the benefits of centralized and decentralized solutions, as well as the required degree of centralization for achieving the optimum point in the network operation.

In general, centralized solutions achieve better accuracy (due to the global view of the decision maker) with the cost of increased signalling and delay for gathering the information in the centralized decision making point. On the other hand, decentralized solutions tend to find suboptimal solutions due to the limited network view, but without the signalling overhead of the centralized approaches. The trade-off analysis indicated that in general centralized solutions are more likely (in most cases this approach has been also followed by METIS project TeCs) to be used; in specific cases with strict time requirements decentralized approaches may be followed as well. A potential alternative, when considering the signalling centralization overhead in UDNs, is the use of hierarchical schemes with several levels of centralization.

4.1.3 Long Time Scale vs. Short Time Scale

The long time scale vs. short time scale trade-off is related to the network's/system's dynamics. In other words, the higher the system's dynamics, the shorter the timescale shall be for identifying the changes in the network components. The performed analysis showed that with short timescales, the system avoids overprovisioning problems with the cost of increased measurements and signalling. Thus, the dynamics of each problem shall be identified for finding the optimum operation timescale; the analysis showed a strong dependency on the problem under consideration and the system dynamics.

The key aspects of this trade-off have also been highlighted by representative examples, regarding synchronization process of the femto cells with the overlaying macro cells in conjunction to the network environment (quality of the measured signals). The analysis showed that if the quality of the signal is bad (the network's special characteristics/dynamics are not extracted) the synchronization process is affected negatively (more time will be required). Similar outcomes have been extracted regarding the nodes clustering in UDNs in relation to the network dynamics (mobility of users, presence of nomadic cells, etc.) which shall be adaptable to network changes. Similarly, resource allocation and scheduling in UDNs shall consider the network dynamics for being as flexible as possible, so as to cover the users' needs before they enter outage zones.

4.1.4 Information Interflow vs. throughput/mobility enhancement

Information Interflow vs. throughput/mobility enhancement trade-off refers to the burden posed to the network by the need for additional information; such information is required by the new sophisticated mechanisms for enhancing either throughput or mobility management. In the 5G mechanisms, the smart decisions will require more detailed inputs. More precision for the additional inputs will be required as well for fulfilling the advanced requirements. However, this shall be examined in conjunction to the benefit gained from the introduction of the advanced schemes with the more information requirements. This will enable to quantify the actual benefit from the introduction of the mechanisms. This will also enable to evaluate whether similar results may be achieved with less precise information but without the heavy communication cost.

The analysis proved that the benefits in the throughput/mobility management shall be combined with the cost in the information exchange. For example, the use of nodes grouping for avoiding the congestions in the signalling channels is beneficial in the networks' uplink, though it has a direct impact on the downlink overhead increase. However, it should be noted that in this case the benefit in the uplink outweighs the drawbacks in the downlink leading to a final positive outcome.

4.1.5 Energy Efficiency vs. Network Capacity and Coverage trade-off,

The energy efficiency vs. network capacity and coverage trade-off refers to the densification approach that will be used in the future networks, for meeting the capacity and coverage requirements. However, it should be considered that the coverage and capacity requirements shall not be met with overprovisioning of resources which leads to unnecessary energy consumption.

The analysis has highlighted the actual trade-off between energy consumption and coverage/capacity via simulations. Additionally, two important aspects have been highlighted:

- The provided capacity should be adapted to the actual demand for enhanced energy efficiency
- The communication schemes in D2D scenarios shall operate in an energy efficient manner in terms of transmitted power while maintaining an acceptable performance levels.

In fact, the two aspects above suggest that for a wireless communications system to be energy efficient it should be operated in such a way that it just meets the experienced end-user QoS. Any additional provided throughput will result in higher energy consumption and thus degrade the system performance in terms of energy efficiency.

4.2 Trade-offs combined analysis

The analysis of the trade-offs that have been presented in this deliverable leads to some useful considerations regarding the key aspects of each trade-off on the one hand and the joint analysis of the trade-offs on the other hand. These could be summarized as follows:

- The aspects of each solution shall be clearly related to the problem spaces and dynamics. This will lead to the efficient network operation with regards to timescales, accuracy, signalling, and energy efficiency.
- The different application domains in METIS have naturally different requirements and KPIs. It becomes evident that when selecting a solution for different application domains it has to be taken into consideration the outlined trade-offs and leverage the disadvantages by carefully selecting the solution.
- Major trade-offs are signalling and complexity which can be derived from information flow vs. throughput/mobility enhancement or centralized/decentralized solutions trade-off.
- Energy efficiency vs. network capacity and coverage captures the ability of the network to adapt to the actual users' needs. Future wireless communications systems will have to be able to instantly adapt its provided service (capacity) to the changing user requirements and meet them exactly with no overprovisioning. Therefore, the trade-off *Energy efficiency vs. network capacity/coverage* is strongly connected with the trade-off *Long time scale vs. short time scale*. The faster the system can adapt the better the energy efficiency.

The latter two considerations highlight the strong connectivity and interdependency of the identified trade-offs. Table 4-1 provides a simplified overview of the connections between them which does not capture all details but can be used as a general guideline when aiming at improved performance or no performance degradation.

	Centralized/Decentralized	Long/Short time scale
Complexity	• Centralized solutions allow for more complex operations • Decentralized solutions increase complexity by requiring additional coordination	• Short time scale adaptations require more computational power leading to higher complexity
Information Interflow	• Centralized solutions increase the Information Interflow as the information needs to be collected • Decentralized solutions increase the information interflow as they usually require coordination among nodes	• Short time scale mechanism exchange more information per time unit
Energy Consumption	• Centralized approaches better adapt to system dynamics	• Time scale should be in the same order as system dynamics

Table 4-1: Simplified interrelations of identified trade-offs involved when aiming at improved performance.

Future work of WP4 should incorporate further considerations for the overall system performance. The timescales and the information exchange shall be considered in a holistic manner. Additionally, the information exchange (i.e., Transmission power, link gains, mobility patterns, exact positioning, etc.) for the several problems that are being tackled may be redundant, thus reducing the overall system overhead.

5 References

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6 APPENDIX

For higher readability and better illustration of the trade-offs present in WP4 we have omitted to give all technical details involved in the main body of this deliverable. Nevertheless, it is of high importance to give the full picture and all assumptions to the investigation. For this purpose the appendix should complement the brief description of the main body with further details.

6.1.1 T4.1-TeC1-A1 – Adaptive Projected Sub-gradient Method (APSM)

T4.1-TeC1-A1: Adaptive Projected Sub-gradient Method (APSM)	
Main idea	**Requirement and cost**
The goal is to efficiently estimate and track the channel gain vector which consists of K_b x K_u channel gains between all transmitters and all receivers. A priori knowledge and measurements are exploited by projecting an estimate of the channel gain vector on some suitably constructed closed convex sets. Sets are constructed based on a priori knowledge such as positions of the nodes and on measurements (e.g., RSRP and interference measurements). Our approach is an extension of standard Projection on Convex Sets (POCS) methods to better track time varying channel gains and to improve the convergence behaviour. At time point, a new estimate of the channel gain vector that is closer to the intersection of closed convex sets as compared to the current estimate is found.	• Channel gains • RSRP measurements to estimate the channel gains locally. • Position/location (relative or absolute) of each device is known to both BS and device itself
Advantages and gains	
• No synchronization is required • Ability for the nodes to leave and join the network smoothly without affecting convergence properties • No need for any node to know its particular neighbours. • Can smoothly exploit both deterministic and statistical knowledge provided that it can be modelled using a closed convex set	
Related to trade-off	
• Complexity vs. performance improvement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	

This TeC is based on online updates with measurements from the system. The performance, i.e. the accuracy of the path-loss prediction, is highly related to the number of measurements and the quality of the measurements. The additional complexity is introduced to the need to collect measurements with higher granularity to reconstruct the interference map more accurately. Therefore, the signalling overhead is increased. The considered TeC is an enabling technique that supports mechanisms improving SINR for users. Thus this TeC indirectly aims at METIS KPI 10 to 100 times higher user data rate, 10 to 100 times higher number of UE devices and 1000 times higher mobile data volume per area.
Qualitative results with respect to the trade-off
The precision of the path-loss prediction (MSE) according to the number of available measurements is investigated. This machine learning technique is also evaluated with respect to the time needed after which a reliable path-loss prediction is possible.

6.1.2 T4.1-TeC1-A2 – Minimum Mean Square Error (MMSE) Estimation

T4.1-TeC1-A2: Minimum Mean Square Error (MMSE) Estimation	
Main idea	**Requirement and cost**
Statistical knowledge about the channel gain vector and measurement uncertainty is exploited. Given some physical-layer measurements (the RSRP, Uplink Interference (ULI) and Downlink Interference (DLI) measurements), an ideal linear model in which the prior distribution of the interference matrix and the uncertainty distribution is Gaussian in linear scale is derived. This model relates the measurements to the channel gain vector and therefore can be used to derive an optimal linear MMSE (LMMSE) estimator for the channel gain vector. Since slow fading caused by shadowing is often assumed to have a log-normal distribution, a more realistic model in which the prior interference distribution is log-normal and the uncertainty distribution is Gaussian in dB scale is used. In this case, the model becomes non-linear, and therefore a closed-form "linearized" MMSE estimator, named linearized log-MMSE (LLMMSE), is derived to estimate the channel gain vector.	• A priori distribution of channel gain vector with mean and covariance matrix • Reciprocity of the channel holds • RSRP measurements • RSSI measurements • ULI and DLI power • Path loss model
Advantages and gains	
• LMMSE is optimal in cases of an ideal Gaussian model for both interference gains and measurement uncertainties • LLMMSE is better suited for realistic scenarios where channel gains and measurement uncertainties are modeled as log-normal random variables	
Related to trade-off	
• Complexity vs. performance improvement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	

This TeC is an alternative to T4.1-TeC1-A1 and thus has the same objective. Therefore, the same statements regarding trade-offs apply. This TeC is based on online updates with measurements from the system. The performance, i.e. the accuracy of the path-loss prediction, is highly related to the number of measurements and the quality of the measurements. The additional complexity is introduced to the need to collect measurements with higher granularity to reconstruct the interference map more accurately. Therefore, the signalling overhead is increased. The considered TeC is an enabling technique that supports mechanisms improving SINR for users. Thus this TeC indirectly aims at METIS KPI 10 to 100 times higher user data rate, 10 to 100 times higher number of UE devices and 1000 times higher mobile data volume per area.
Qualitative results with respect to the trade-off
The precision of the path-loss prediction (MSE) according to the number of available measurements is investigated. This machine learning technique is also evaluated with respect to the time needed after which a reliable path-loss prediction is possible.

6.1.3 T4.1-TeC1-A3 – Interference Identification using multi-layer inputs

T4.1-TeC1-A3: Interference Identification using multi-layer inputs	
Main idea	**Requirement and cost**
The idea of the proposed scheme is to combine available information from several network points. The information will be combined in the IIE, which undertakes the identification which are the potential aggressors in the interferer. The physical and network topology information will be used to identifying the proper path loss model. The latter will facilitate the estimation of the degree that each source (interferer) affects the target node (victim).	• Inputs o RSRP o RSRQ o Position o Location-environment (i.e., shopping mall, stadium, etc.) • Introduction of IIE • New signalling required (hasn't been quantified yet)
Advantages and gains	
The scheme is based on a distinction of uplink and downlink interference cases. Precise of aggressor list compared to eICIC schemes. This preciseness will enable targeted problem (interference) solving; also the IIE given an intuitive view of the degree each aggressor affects the victim.	
Related to trade-off	
• Complexity vs. performance improvement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	

The introduction of a centralized entity, the Interference Identification Entity (IEE) increases the communication and computation complexity. IIE requires information from several network elements in the vicinity (UEs, (H)eNBs, HeNB aggregator) so as to identify source of interference. Thus signalling overhead is increased. In addition, IIE dinstincts uplink and downlink transmission cases so as provide precise results, so extra computational overhead is considered. The considered TeC aims directly at METIS KPI 10 to 100 times higher user data rate, 10 to 100 times higher number of UE devices and 1000 times higher mobile data volume per area.
Qualitative results with respect to the trade-off
The precision of aggressor list produced by IIE prevails compared to conventional eICIC schemes. Preciseness will enable targeted problem (interference) solving; also the IIE given an intuitive view of the degree each aggressor affects the victim.

6.1.4 T4.1-TeC2 – Unified resource allocation framework for D2D discovery

Main idea	Requirement and cost
The main idea is a unified framework with the same pre-defined steps to be used for device discovery both under network coverage and out of network coverage. Under network coverage, the eNBs own the discovery resources and manage their allocation in a totally or a semi centralized or fully decentralized way. In the absence of the cellular infrastructure, there is either a clustering approach or a device-centric approach. In the clustering approach, cluster heads are elected to take over the eNB functionalities. CH nodes continue controlling the resource utilization. Alternatively, the discovery can be performed in a totally autonomous way by a device-centric approach where all devices have the same capabilities and then only best effort type of services are provided.	Depending on the scenario, the discovery procedure may need one or many of the following information: • UE position, UE capabilities, QoS requirements, • Direct Channel quality between devices which could be estimated based periodic measurements reported by the devices.
Advantages and gains	
The framework allows a seamless transition between both scenarios and smooth integration of clusters and cells (where available) and to take advantage of and extend the concept of underlying D2D communications.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.5 T4.1-TeC3-A1 – Distributed Channel State Information Based Mode Selection for D2D Communications

Main idea	Requirement and cost
The key idea is based on the observation that mode selection and the management of resources between the cellular and D2D layers are inherently intertwined. Therefore, in contrast to state of the art, the proposed MS	• Each device must estimate its path loss (large scale fading) to its serving BS and to its peer device. These

scheme distinguishes (1) cellular mode, (2) direct mode with dedicated D2D resource and (3) direct mode with cellular resource reuse. Two versions of this basic idea can be implemented: the balanced random allocation (BRA) utilizes the available resources adaptively to the load in the cellular and D2D layers, while the cellular protection algorithm (CPA) protects the cellular layer from the interference caused by the D2D layer.	pieces of information must be made available to the serving BS by means of appropriate signalling at the time of scale of the large scale fading (e.g. 100 ms, similar to the time scale of handover measurements).

Advantages and gains

The advantage of the BRA and CPA algorithms is their scalability in terms of the number of devices both at the cellular and D2D layers due to the fact that they rely on large scale fading measurements and eliminate the need for full channel state information (i.e. no cross-D2D pair CSI values are needed). Ultimately, when used in conjunction with utility optimizing power control, BRA and CPA takes advantage of the proximity-, reuse- and hop gains of network assisted D2D communications.

Related to trade-off

- Centralized vs. Decentralized
- Complexity vs. Performance Improvement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

Mode selection (MS) and resource allocation (RA) jointly determine the communication mode and the set of radio resources to be used by device-to-device (D2D) and cellular users in an integrated cellular-D2D network. MS and RA can be exercised in a centralized manner, whereby the cellular BS controls MS and RA. Alternatively, MS and RA can be performed jointly by the BS and the devices that form the D2D communication links.

TeC3-A1 exploits limited channel state information to select one of three possible communication modes for D2D capable devices that are in the proximity of one another. Forced cellular mode implies the traditional cellular (via the cellular BS) communication mode, D2D mode without cellular resource reuse allows proximity users to use a direct D2D link with dedicated resources (no overlap with cellular users), while D2D with resource reuse allows D2D links to use cellular resources that are used by the cellular layer. TeC3-A1 takes into account channel state information that is available locally at D2D receivers and at the BS, resource availability and current load situation to select one of these three communication modes. TeC3-A1 can be advantageously combined with various other RRM and in particular power control (PC) algorithms to fully take advantage of D2D communications in terms of energy and spectral efficiency as illustrated by Fig1.

MS and RA are the key enablers of D2D communications and contribute to the METIS goals on 1000 times higher mobile data volume per area and 10 times longer battery life for low power devices.

Qualitative results with respect to the trade-off

Centralized MS and RA with full CSI available at a central entity such as the cellular BS may outperform a distributed MS algorithm at the expense of scalability problems and excessive measurement result signaling. On the other hand, decentralizing MS and RA may lead to suboptimal communication mode selection and resource allocation to the cellular and D2D layers in terms of spectral and energy efficiency [FBPPJA13], [PFMB14], [FSS14].

Quantitative (graphs, curves, etc.) results with respect to the trade-off

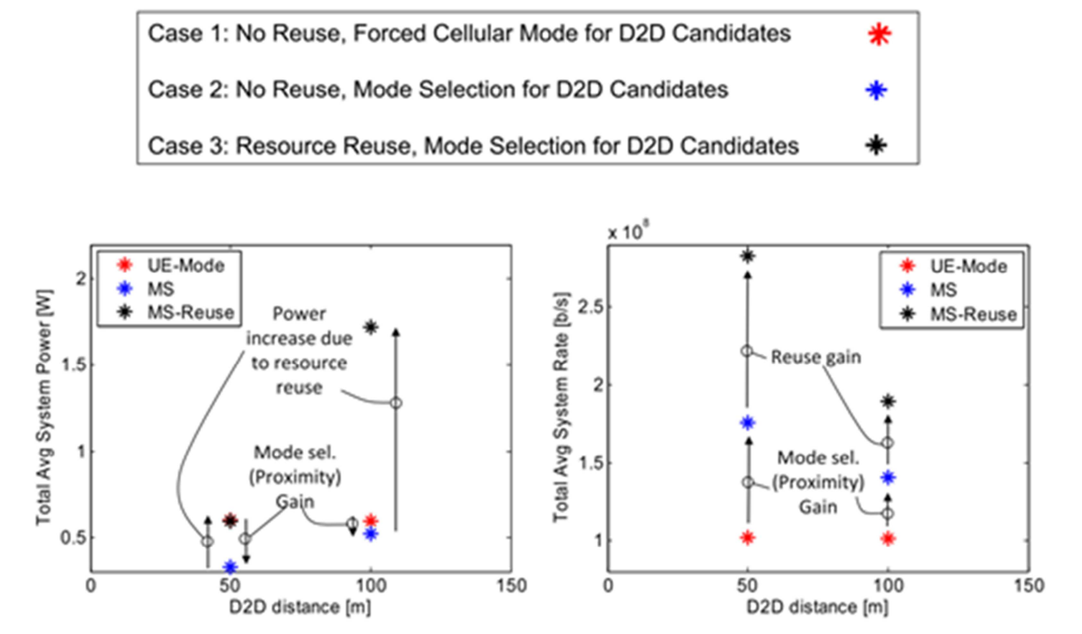


Figure 6-1: Total invested power and system throughput without D2D communication

The total (uplink) invested power and the total system throughput (averaged over the Monte Carlo simulation instances) without D2D communication (no resource reuse; forced cellular communication, (Case 1), with CSI based mode selection but dedicated orthogonal resources for the D2D layer (Case 2) and CSI based mode selection with resource reuse (Case 3). All users use the utility function maximizing power control algorithm of T4.1 TeC5-A1/A2.

T4.1-TeC3-A1 can be combined with various other RRM and in particular power control algorithms to fully take advantage of D2D communications in terms of energy and spectral efficiency as illustrated by Figure 6-1.

6.1.6 T4.1-TeC3-A2 – Location-based mode selection for D2D

Main idea	Requirement and cost
The main idea is to utilize users' location information to perform mode selection for D2D candidate users. Based on distance and path loss estimation, the BS decides whether the D2D candidates can transmit in D2D mode or cellular mode. The D2D mode is selected only if it is beneficial from the users' perspective.	• Users geographical location • Increased signalling due to the need for mode selection • Potential increase in signalling in the case when the user provides the location information.
Advantages and gains	
The main advantage of the proposed location based mode selection method is that no channel state information is required from the D2D candidates, thus no additional signaling from the algorithm itself is introduced. Other advantage is the seamlessness of the method i.e. D2D candidates don't have any part in the initiation of the mode selection process.	

Related to trade-off
• Centralized vs. decentralized • Information interflow vs. throughput/mobility enhancement • Energy Efficiency vs. Network Capacity and Coverage
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
Centralized approach for mode selection allows for a network-level control over UEs transmission modes in comparison to neighborhood-level in the decentralized case. It also requires less signaling information to be exchanged by the users as compared to the distributed mode selection approach. However, location information based approach also requires information interflow for operation. For example if satellite based positioning system is used UEs has to report their positions to the central entity thus increasing the signaling overhead. Location based mode selection in its operation also takes into account energy efficiency from the user perspective. The D2D mode is selected only if it is beneficial for the UE and it doesn't severely disturb the operation of cellular users. The TeC has the potential to increase the number of connected users and thus aims directly at METIS KPI 10 to 100 times number of devices. Additionally by selecting the D2D mode over the cellular mode the decrease in energy consumption can be achieved thus this TeC also aims at the 10 times longer battery life.
Qualitative results with respect to the trade-off
The amount of signalling overhead introduced by this approach depends on how the location information is obtained. In the case of using satellite positioning system the user has to report its position to the central entity. In the case of measurement based positioning the entities involved in the measurements have to exchange the results of the measurements. Nevertheless the envisioned increase in signalling is expected to be low and far less than in the case of decentralized approach.

6.1.7 T4.1-TeC4-A1 – Multi-cell coordinated and flexible mode selection and resource allocation for D2D

Main idea	Requirement and cost
Proposed solution focus on optimization of overall system performance and efficiency through solutions encompassing both cellular transmission and network-facilitated D2D. Performance is evaluated based on the different level of centralization.	• Channel state and buffer information needs to be additionally signalled from small cell to Macro in the case of a centralized approach • CSI information and RRM decisions for D2D transmission are delayed by the small cell-Macro-small cell exchange
Advantages and gains	
• Improved spectrum utilization in flexible UL/DL TDD mode due to the optimal allocation of time/frequency resources	

- Lower packet transmission delay (initial investigation shows up to 45% performance improvement in TC2 indoor) comparing to fully distributed scheme

Related to trade-off

- Centralized vs. decentralized
- Long time scale vs. short time scale

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

T41-TeC4-A1 focus on holistic analysis of resource allocation for transmission of data between devices including direct and indirect mode. Research is carried out in TDD mode with flexible UL/DL usage. It directly affects METIS objectives of 1000x higher traffic and 10-100x higher user data rates. It relates to trade-off investigations in a two-fold manner. Performance of both centralized and decentralized resource allocation schemes is analyzed. Additionally, long term and short term mode selection (between direct and indirect-via-infrastructure transmission) is investigated.

Qualitative results with respect to the trade-off

Qualitative results are related to signaling related to measurements and information exchange necessary for centralized and decentralized operations. In case of long term and short term mode selection, similar estimation will be needed.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

First performance analysis of centralized/decentralized resource management schemes together with fast (based on previous TTI SINR) and slow (pathloss-based) mode selection is available. A bias to favor D2D decisions over DID (device-infrastructure-device or indirect) is applied in fast mode selection to minimize the delay. Reuse of resources between D2D and cellular users is enabled. Results indicate that gains of around 14% in D2D packet delay reduction at 95th percentile are possible from fast mode selection over slow mode selection. The centralized scheduler performs 8% better than the decentralized one for both mode selection cases (see green and red curves).

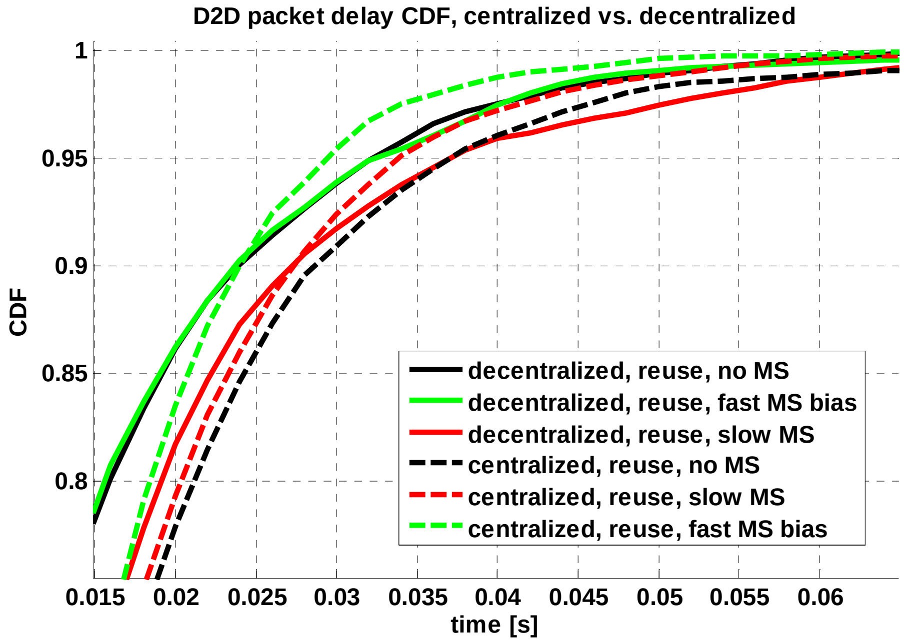


Figure 6-2: D2D packet delay CDF

The centralized scheduler sacrifices 13% of D2D packet delay for the case without mode selection (direct D2D only, see black curves) while achieving performance gains between 10%-16% in cellular DL and UL packet delay through smart D2D scheduling in all D2D reuse schemes (see figures below).

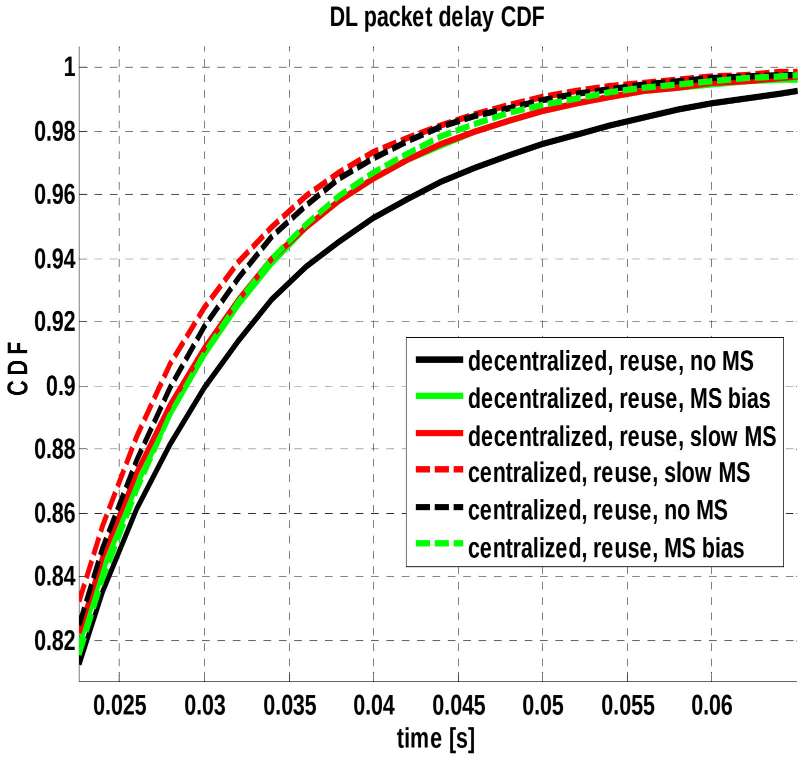


Figure 6-3: Downlink delay CDF

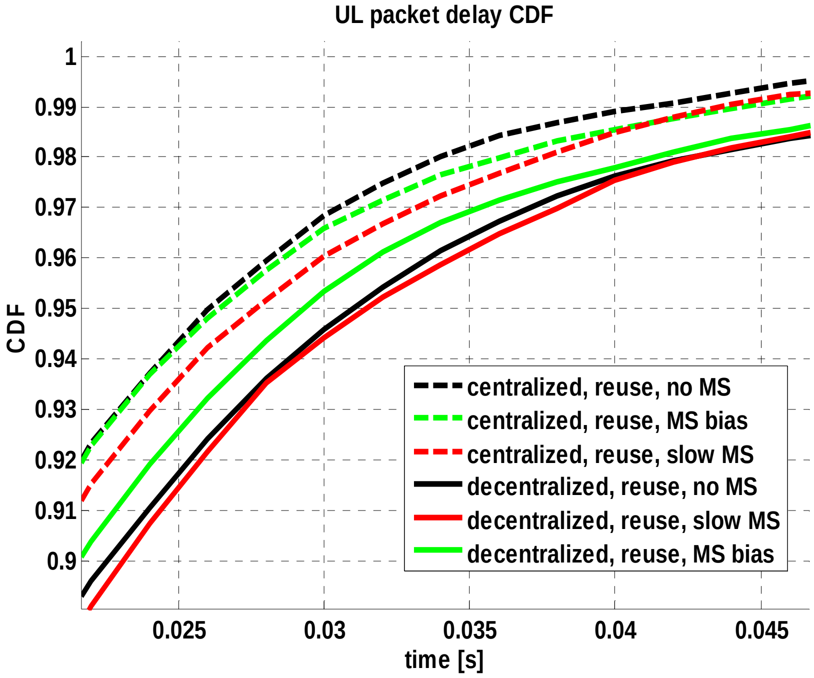


Figure 6-4: Uplink delay CDF

6.1.8 T4.1-TeC4-A2 – Location-based D2D resource allocation

Main idea	Requirement and cost
The main idea is to utilize users' location information for resource allocation that mitigates interference from D2D overlay. The BS uses the distances between network entities to estimate corresponding path loss and SIR value. Based on this information the BS uses the distance maximization approach to find the best candidate for resource sharing. Additionally this scheme allows different D2D pairs to share the same cellular resources.	• Users geographical location • Model for path loss estimation • Potential increase in signalling in the case when the user provides the location information.
Advantages and gains	
This simple resource allocation method requires no channel state information from the D2D users due to the fact that location information is used to estimate the channel. Centralized approach gives more control of D2D links and as a result allows for better control of interference caused by D2D communication. Moreover the proposed method allows for scheduling multiple D2D pairs on the same frequency resources thus potentially further increasing the capacity of the network.	
Related to trade-off	
• Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
Location based resource allocation requires that a central entity has a knowledge on users positions in the network. This means that information interflow is required, which leads to an increased signaling overhead. This slight increase in signaling is a price to be paid for increase in cell throughput and number of connected users. The TeC has the potential to increase throughput and thus aims directly at METIS KPI 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.	
Qualitative results with respect to the trade-off	
The precision of the location information is significant in its operation; the better the precision the better performance enhancement can be achieved. In ideal case the performance of the location based resource allocation based method can match the performance of the resource allocation that is based on full knowledge of the network (channel state etc.)	

6.1.9 T4.1-TeC4-A3 – Context-aware resource allocation scheme for enabling D2D in moving networks

Main idea	Requirements and cost
This TeC exploits the properties of V2D communications (short range, periodicity …) in order to enable the integration of automotive services in	• Channel (environment) model for the specific network deployment • Quantized/crude position

5G networks. It relies on cell partitioning and spatial resource reuse in order to enable simple RRM and efficient signaling in a D2D underlay. Hereby, scheduling decisions are based on crude location information instead of unreliable/infeasible channel measurements.	information (zone index) • Effort on network planning • Reduced frequency/user diversity gain in the primary network (The loss is expected to be marginal)
Advantages and gains	
• Support for services with stringent QoS requirements in the D2D underlay • Minimized signaling overhead • Need for CSI avoided (of advantage since CSI cannot be collected reliably and efficiently in a highly mobile environment) • Low scheduling complexity Integration of any scheduling policy possible	
Related to trade-off	
• Complexity vs. performance improvement • Long time scale vs. short time scale • Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
Applying a cell partitioning approach with certain resource reservation assignments, aims at reducing the complexity of interference management in a D2D-enabled cellular network. Above all, it allows for the significant reduction of the required channel measurements (and reports) and enables D2D links between fast moving nodes. Moreover, the TeC allows for the efficient implementation of services with strict QoS requirements exploiting information about their characteristics. In the primary application scenario – automotive safety applications – this leads to (semi-)persistent scheduling in a long term. T4.1-TeC4-A3 is focused on the implementation of automotive services in a D2D underlay and, therefore, targets a reduction of the end-to-end latency and accommodation of a (very) high number of users. Hence, this TeC contributes towards the METIS objectives of 1000 times higher mobile data volume per area, 10 to 100 times higher typical user data rate, and 5 times reduced end-to-end latency.	
Qualitative results with respect to the trade-off	
In comparison to state of the art approaches, this TeC would significantly reduce the signalling overhead in the case of periodic D2D communication. At the same time it would enable D2D communication between fast moving network nodes. Resource allocation in long term further contributes to the reduction of the signalling overhead. In result, the achieved performance might be sub-optimal in terms of total network capacity, but will, nevertheless, be sufficient for the support of some desired services.	
Quantitative (graphs, curves, etc.) results with respect to the trade-off	
• System level simulations showing the advantages of this TeC in terms of better support of mobility and QoS will be available soon. • Preliminary link level simulations are already available. However, these do not cover all the trade-off aspects. The figure below illustrates the better support of mobility and higher user density provided by the TeC as compared to a reference scheme. The discrete pdf of the number of allocated resource blocks (RBs) to each terminal in the D2D underlay (vehicular terminals or V-UEs) is presented. Note that a specific service that only requires 1 RB per time instance is assumed. The results show that the consideration of the service characteristics enables this TeC to provide the desired	

performance in all cases. At the same time, the reference scheme illustrates significant loss of performance with the increased user density.

***Reference Scheme:** [ZHS10] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient resource allocation for device-to-device communication underlying LTE network"

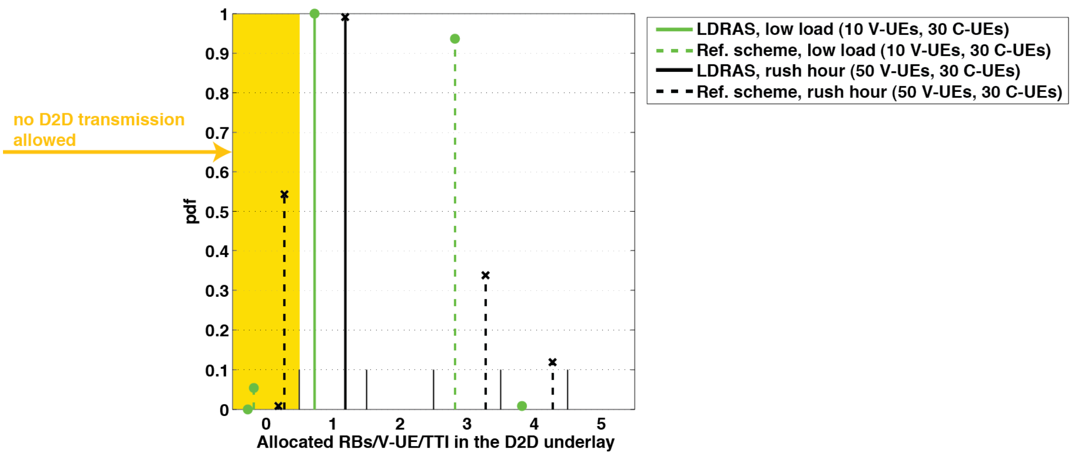


Figure 6-5: number of allocated RBs per UE in D2D underlay

6.1.10 T4.1-TeC4-A4 – Network assisted resource allocation for direct V2V communication

<table>
<tr><th>Main idea</th><th>Requirement and cost</th></tr>
<tr><td>A cluster concept for vehicular safety applications where the cellular network nodes assist few vehicles or CHs to take over the control of the direct V2V communications for a group of attached vehicles. The role of the CH is to control the vehicles within its cluster, handles the cluster joining and leaving requests, and manages the radio resources on the basis of resource assignment received from the cellular node. The CH periodically updates the network nodes with the cluster description specifying the characteristics of the corresponding cluster such as average position, average velocity and the direction of the cluster members.</td><td>Position and mobility information of vehicles
Density information</td></tr>
<tr><th colspan="2">Advantages and gains</th></tr>
<tr><td colspan="2">Provides a fair and predictable channel access since the real time context information is used to adjust the network level resource assignment
Increases the reliability of vehicular communications
The adaptation of safety message transmission parameters (frequency, power) can be easily performed by the network nodes that are already collecting useful context information about the movements of the vehicles (location, directions, speeds) and the vehicular density.
The traffic generated by safety applications could be split between the cellular spectrum for the major part of the control traffic and the dedicated V2V spectrum for safety data traffic.</td></tr>
</table>

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.11 T4.1-TeC4-A5 – RB allocation and power control scheme for D2D-based V2V communications

Main idea	Requirement and cost
This TeC studies the RB allocation and power control scheme when applying D2D underlay network to V2V (safety-related) applications. Under the condition of satisfying V-UEs' strict QoS requirements on latency and reliability, this TeC aims at maximizing C-UEs' sum rate with some fairness constraint. To do so, the RB allocation and power control scheme can be implemented in a long-term and centralized manner. Besides, a short-term and (semi-) distributed power adjustment method is also possible.	• Channel knowledge on large scale fading effects including path loss and shadowing. • Central controller, e.g., the eNB. • Potential increased signalling overhead since V-UE receivers need to report their involved channel information (in terms of large scale fading) to the central controller.

Advantages and gains
• Improved overall system performance, i.e., increased C-UEs' sum rate with guaranteed V-UEs' latency and reliability requirements. • Acceptable complexity and signaling overhead Possible lower signaling overhead and higher diversity gain by adopting short-term and (semi-) distributed power control algorithm.
Related to trade-off
• Complexity vs. performance improvement • Centralized vs. decentralized • Long time scale vs. short time scale
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
This TeC designs RRM scheme, i.e., RB allocation and power control algorithm, for D2D-based V2V communications, such that cellular UEs' sum rate is maximized under the condition of satisfying vehicular UEs' QoS requirements on latency and reliability. This TeC aims at improving the system performance with an acceptable complexity. To do so, the eNB can be required to conduct centralized & long-term RB allocation and power control. Alternatively, a (semi-) distributed power adjustment scheme at each UE is also possible, which will then be in short-term time scale. This TeC aims at the METIS KPI 10 to 100 times higher typical user data rate, and 5 times reduced end-to-end latency.
Qualitative results with respect to the trade-off
This TeC considers actual requirements on vehicular UEs and traditional cellular UEs separately, and then designs RB allocation and power control scheme to satisfy the requirements of both types of UEs. In this way, the overall system performance can be improved with moderate algorithm complexity. This TeC may be implemented by both centralized & long-term and (semi-) distributed & short-term manners. The former leads to simpler implementation and faster convergence; while the latter gives rise to lower signalling overhead and better utilization of fading channels. The detailed comparison between the two

approaches is under investigation.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

- The first analysis of the trade-off between complexity and performance improvement is shown as below. In this figure, under the condition of satisfying each vehicular UE's requirements on 1) the number of allocated RBs (i.e., 3); and 2) the SINR constraint on each of its used RBs (i.e., 22.3 dB), the cellular UEs' sum rates are compared among different schemes. The scheme in [ZHS10] (referred to as "modified-[1]" in the figure) is simple and intuitive. The scheme in [FLYLFL13] (referred to as "modified-[2]" in the figure) is more advanced in RB allocation but unsophisticated in power control. Notice that, to fit theirs schemes into our framework and make the comparison as fair as possible, we have done some modifications to them. As illustrated in this figure, the proposed SRBP scheme shows obvious performance improvement.

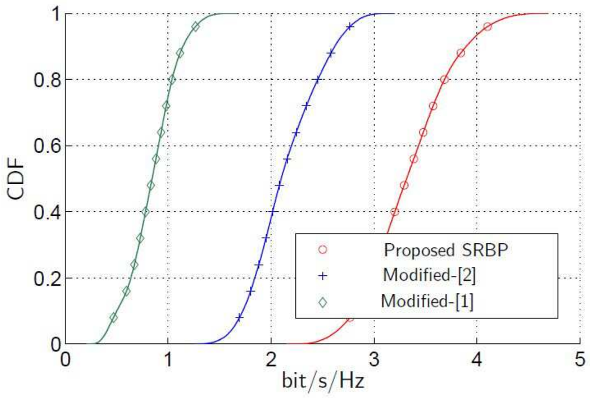


Figure: 100 RBs, 10 cellular users, 30 V2V pairs.

Figure 6-6: Spectrum efficiency of cellular users under the condition of satisfying V2V users' requirements

- More simulation results will be available soon regarding the trade-off analysis between centralized and decentralized, and between long time scale and short time scale.

6.1.12 T4.1-TeC5-A1-A2 – Joint Methods for SINR Target Setting and Power Control for D2D Communications

Main idea	Requirement and cost
The key idea of joint SINR target setting and power control is to iteratively set SINR targets and associated transmit power levels both for the cellular and D2D layers. The joint setting of the SINR targets and powers aim at maximizing a system wise utility function that takes into account both spectral and energy efficiency. Thanks to the design of this TeC, the fundamental trade-off between spectral and energy efficiency can be tuned by a parameter whose value governs whether the system operates in a spectral or energy efficient mode or balances between these two objectives.	• Each device must estimate its path loss (large scale fading) to its peer device and continuously measure the total received power (similarly to the existing LTE RSSI). • The main cost of this TeC is the number of iterations required to reach a near optimal SINR target and associated power level. However, confining the number of iterations implying

	sub-optimality is a possible engineering trade-off.
Advantages and gains	
The main advantage of T4.1-TeC5-A1-A2 is that they can determine the transmit power levels at the D2D and cellular layers in a near optimal fashion in terms of spectral and energy efficiency. Alternatively, T4.1-TeC5-A1-A2 can be used together with existing power control algorithms such as the LTE open loop path loss compensating PC scheme, in which case the overall system performance may be decreased compared to the near optimum obtained by T4.1-TeC5-A1-A2. On the other hand such a hybrid PC scheme allows for the gradual introduction of D2D communications into evolving cellular networks.	
Related to trade-off	
• Energy efficiency vs. Network capacity and coverage • Centralized vs. Decentralized	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
T4.1 TeC5 adaptively sets the signal-to-interference-plus-noise-ratio (SINR) target (TeC5-A1) and adjusts the transmit power levels (TeC5-A2) in an integrated cellular-D2D environment, and as such, it is a key technology component to achieve high spectral and energy efficiency and, at the same time, to protect the cellular layer from excessive interference. This is especially important when the cellular and D2D layers share common or overlapping spectrum resources. Such resource sharing can be controlled by closely related D2D mode selection and resource allocation algorithms such as those of T4.1-TeC3-A1. Unlike the state of the art power control solutions, TeC5-A1/A2 is based on a distributed utility maximization approach that is tunable to balance between spectral and energy efficiency. This is made possible by a single parameter that can be configured at the devices or signalled dynamically to the devices by the cellular BS. For both the cellular and the D2D layer, the utility maximizing power control algorithm (“utility Max. PC”) can significantly improve the achieved SINR levels and thereby the achieved user bit rates. TeC5-A1/A2 is closely related to the goal on 1000 times higher mobile data volume per area. As clearly visible in Figure 1, the achieved SINR levels increase depending on the geometry, and depending on the availability of proximity users in the coverage are of a cellular system.	
Qualitative results with respect to the trade-off	
TeC5-A1/A2 can push the individual cellular and D2D users’ spectral efficiency to higher levels than with legacy power control technologies by adaptively taking into account the geometry and traffic load in the system without the need for excessive signaling or centralized decisions. The overall spectral efficiency of the system depends on a parameter that controls the transmit power levels that users will use, and thereby the overall energy efficiency of the system [FBPPJA13], [PFMB14].	
Quantitative (graphs, curves, etc.) results with respect to the trade-off	

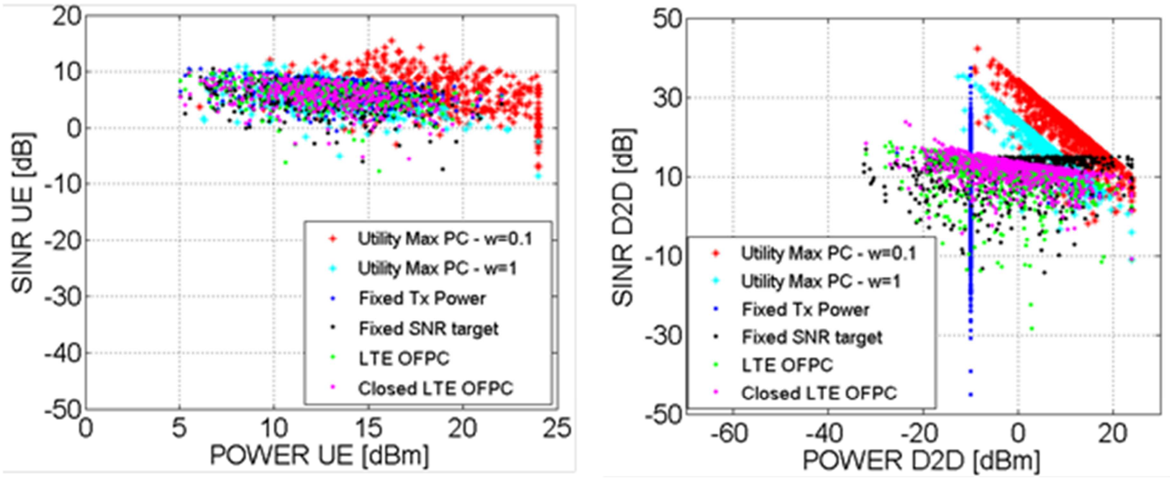


Figure 6-7: SINR of cellular user (left) and D2D user (right)

TeC5-A1 and A2 deals with both cellular user equipment (denoted “UE”) and device-to-device users (“D2D”) in an integrated cellular-D2D system. These scatter plots describe the achieved SINR and the invested transmit power levels for cellular user equipment (UE) (left) and D2D users (right) when they are allowed to use the same or overlapping spectrum. The utility maximizing joint SINR target setting and power control algorithm of TeC5-A1 and A2 is compared with legacy (LTE) power control algorithms in terms of invested power and achieved SINR.

6.1.13 T4.1-TeC5-A3 – Location-based power control algorithm for D2D

Main idea	Requirement and
The main idea is to utilize users’ location information to set the limits for transmit powers of D2D users sharing resources with cellular users. The boundaries are set based on distance and path loss estimations between entities sharing the resources. The upper boundary ensures that cellular transmissions aren’t severely disturbed, whereas the lower boundary can be used for initial transmit power set up.	• Users geographical location • Model for path loss estimation • Potential increase in signalling in the case when the user provides the location information.
Advantages and gains	
The advantage of this simple power control method is that it requires no channel state information from the D2D users to derive the boundaries for D2D users transmit powers. However, the main purpose of this method is to set up initial transmit power levels for D2D pair and should be used on top of either legacy power control algorithms or power control algorithms proposed by METIS.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.14 T4.1-TeC6-A1 – Coordinated fast uplink and downlink resource allocation in UDN

Main idea	Requirement and cost
Considered approach proposes centralized RRM mechanism where macro cell controls the small cells using over the air signaling. Small cell reports to macro buffer and channel state information on the small cell-UE link and macro feedbacks scheduling and power constraints to small cell that operates in flexible UL/DL TDD mode.	• Channel state and buffer information needs to be additionally signalled from small cell to Macro • CSI information and RRM decisions are delayed by small cell-Macro-small cell transmission

Advantages and gains
• Improved spectrum utilization in flexible UL/DL TDD mode due to the optimal allocation of time/frequency resources • Lower packet transmission delay (initial investigation shows up to 43% performance improvement in TC2 indoor) comparing to fully distributed scheme CSI and buffer information gathered in central processing point (macro) which could use it for e.g. CoMP processing
Related to trade-off
• Centralized vs. decentralized
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
T4.1-TeC4-A1 focus on holistic analysis of resource allocation for transmission of data between devices including direct and indirect mode. Research is carried out in TDD mode with both fixed and flexible UL/DL mode. It directly affects METIS objectives of 1000x higher traffic and 10-100x higher user data rates. The trade-off investigation here is comparison between centralized and decentralized resource allocation schemes in ultra-dense deployment of small cells.
Qualitative results with respect to the trade-off
Centralized vs decentralized trade-off w.r.t signaling measurements and information exchange necessary for centralized and decentralized radio resource management.
Quantitative (graphs, curves, etc.) results with respect to the trade-off
First performance analysis of centralized/decentralized resource management schemes is available. Results comparing the packet delay performance between centralized and decentralized schemes in flexible uplink and downlink switching are shown for two different scenarios. A short scheduling slot of 2ms is assumed in all the results, by making use of short 0.25ms TTI. Scenario A: Best case deployment where the small cell BSs are placed in the center of each room. The simulation results for this case are shown in Figures Figure 6-8 and Figure 6-9. It is observed that no significant performance improvement is obtained with centralized scheduling, wherein a brute-force search performs cell muting for interference coordination and link scheduling at the same time.

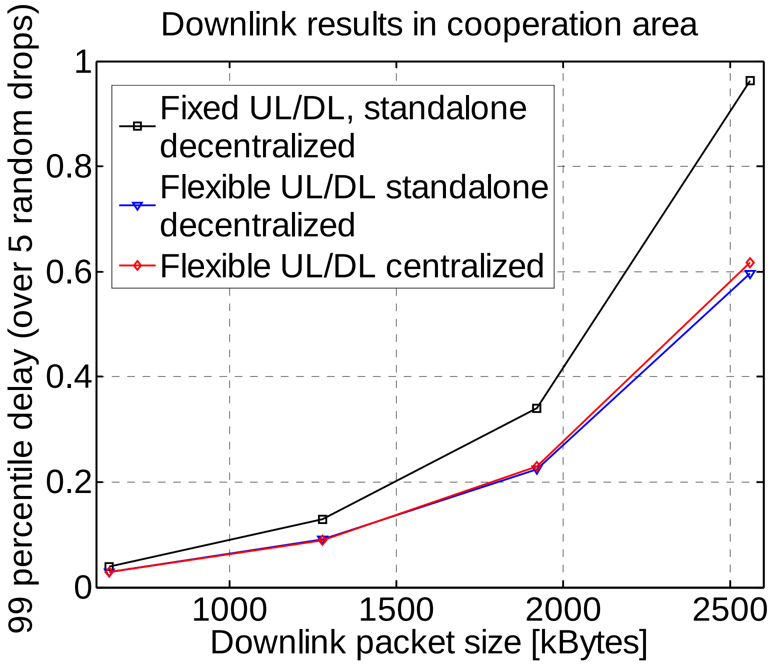


Figure 6-8: Downlink packet delay in Scenario A

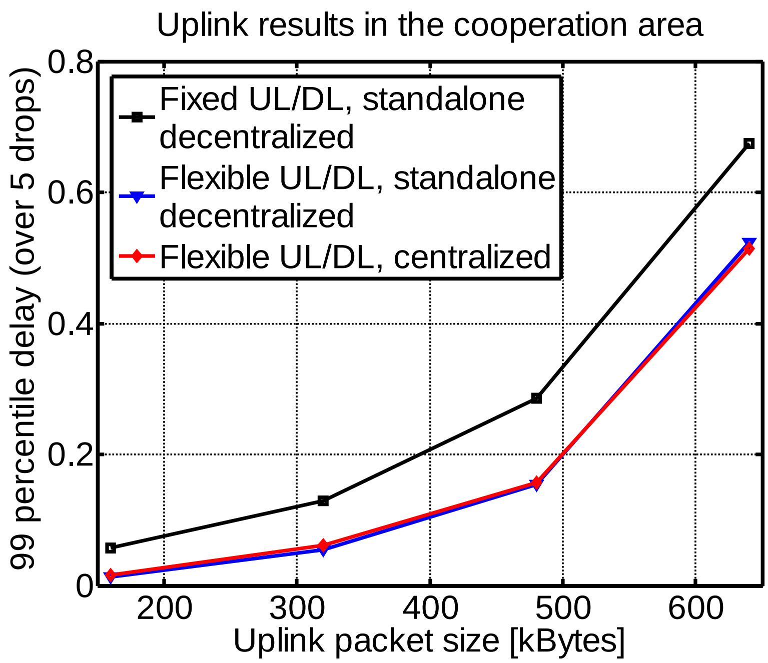


Figure 6-9: Uplink packet delay in scenario A

Scenario B : Unplanned deployment where small cell access points may be placed anywhere randomly. Significant performance improvement around 27 % is observed in this case with centralized scheduling, mainly obtained from interference mitigation of few severe interfers through muting and optimal link scheduling at the same time. See Figures Figure 6-10, Figure 6-11

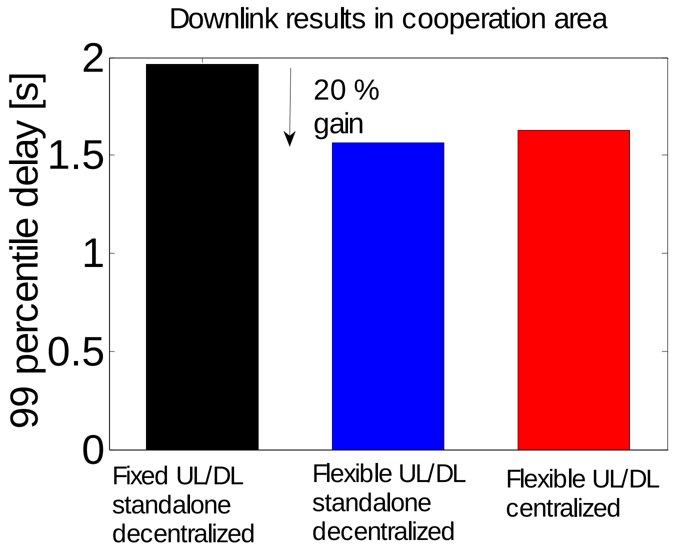


Figure 6-10: Downlink packet delay in scenario B

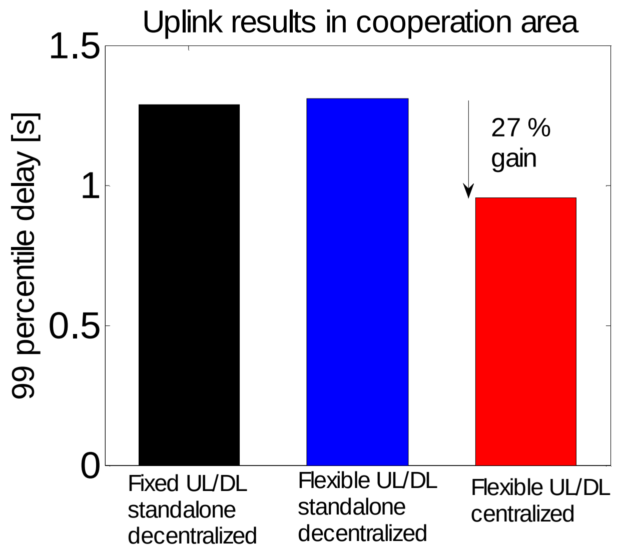


Figure 6-11: Uplink packet delay in scenario B

6.1.15 T4.1-TeC6-A2 – Out-of-band advanced block scheduling in heterogeneous networks

Main idea	Requirement and cost
Use TDD for coordinating FDD communications among the small cells and the macro layer and provide a synchronization reference for the small cells. Interference among small cells is not addressed, only between macro and small cells.	• Details about radio resources to be used in the next frames must be provided by the scheduler of the macro BS, TDD. • Simultaneous operation of FDD + TDD. • Separate TDD transmitter at the macro BS, and TDD receiver at the small cell.
Advantages and gains	
• Enhanced inter-cell coordination.	

• Re-use of spare resources by small cells in low to medium load conditions. • Good coverage of coordination information if a smaller bandwidth is employed for the TDD link compared to that in FDD. • Over-the-air synchronization of small cells with no need to upgrade backhaul lines.
Related to trade-off
• Centralized vs. decentralized • Long-time scale vs. short-time scale
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
Traditional approaches for coordinated operation of multiple cells require centralization of resources to a certain extent, thus leading to complex inter-cell information exchange mechanisms in the data and control planes. Traditional coordinated scheduling mechanisms rely on control plane information being exchanged by the relevant nodes (mainly the degree of resources occupation in the next TTIs). In this sense, backhaul delays should be low enough to allow for coordinated scheduling decisions within short-time scales. In addition these techniques expect a certain degree of centralization so as to coordinate resources from given nodes (usually from the macro layer), which the others should follow. As an alternative, this TeC allows over-the-air scheduling information exchange between nodes, thus enabling very short-time scale coordination if desired. In addition, scheduling coordination can take place in a more or less centralized way without incurring in heavy upgrades for the backhaul infrastructure, by only changing the time scale for the reporting of scheduling information. The granularity of the scheduling information carried by the TDD link allows for a trade-off between long-time scale (for reduced signalling) and short-time scale (for better scheduling coordination). Similarly, the nodes which are signalling the scheduling information can belong to the macro layer (for more centralized schemes) or can also be from other layers (micro, pico… etc.) thus leading to a trade-off between centralized and decentralized operation.
Qualitative results with respect to the trade-off
The short-time scale vs. long-time scale trade-off can be shown by analyzing the amount of scheduling information to be sent per each TTI. It can be expected that detailed scheduling information per TTI will be sent without starvation of the TDD resources even with low system bandwidths, thus leading to very fast scheduling coordination. However long time scales could also be possible if the traffic does not change significantly over several TTIs, in order to save TDD resources. The centralized vs. decentralized trade-off can be shown by observing the effects of allowing more or less cells to send their scheduling information by TDD. Centralized schemes should rely on few macro cells leading the resources assignments, while the others should adjust their transmissions to such information. Decentralized schemes would allow more cells to send their scheduling information in UDN scenarios. The advantage of one or the other scheme would depend on the degree of densification; with decentralized schemes being (in principle) favored over centralized ones in UDN.

6.1.16 T4.1-TeC6-A3 – CSI-based coordination scheme for Macro or small cells with non-coherent JT CoMP

Main idea	Requirement and cost
The proposed approach addresses how the large coherence bandwidths available in small cells could be allocated to the users. Should the frequency allocation be a dedicated resource (DR) or a shared resource (SR) between users or should it be a partly dedicated and partly shared is investigated under downlink NC JT-CoMP with CSIT only at the UEs.	• CSI on the Receiver (CSIR) only at the UEs and the BSs know what UEs to schedule for non-coherent joint transmission CoMP with continuous transmission • For retransmissions, the HARQ feedback is available at the coordinating BSs

Advantages add gains

- Optimizing for the best initial transmission rate, it is observed that at low SNR, sharing frequency resources between users is superior in terms of sum-throughput, while at high SNR dedicating resources is better.
- Any ratio of dedicated and shared resource is suboptimal, other than having completely dedicated resource or completely shared resource.
- CSI in the Transmitter (CSIT) feedback is not required, leading to efficient air-interface usage with NC JT CoMP.
- Adaptive power allocation is not required.
- The long term throughput favours fast fading conditions, where the channel changes in subsequent retransmission due to HARQ.
- The delay due to HARQ is not significant

Related to trade-off

- Centralized vs. decentralized
- Long time scale vs. short time scale

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

Conventional coherent JT-CoMP systems require CSI at the transmitter (CSIT), and that the BSs need to forward the CSI to the central unit to obtain the precoding weights for interference mitigation. In ultra-dense networks, with more nodes, the signaling data rate might be comparable to the user data rate, leading to severe overhead in signaling information. In our proposed approach, we consider non-coherent (NC) JT-CoMP where the CSI is only required at the receiver. This approach reduces the signaling overhead, leading to a better usage of the air-interface. Thus, unlike conventional coherent JT-CoMP, a decentralized approach is possible, as the CSI only needs to be available at the users. However, scheduling the users for NC JT-CoMP requires a centralized decision.

In this work, we consider NC JT-CoMP with CSIR in small cells, where large coherence bandwidth chunks are available due to small delay spread. We address the trade-offs on how to allocate these frequency resources to the users, and also the value of retransmissions (time) is addressed in terms of delay and transmission rate.

Qualitative results with respect to the trade-off

In the above mentioned setup, optimizing for the initial transmission rate, overlapping or sharing the same frequency resources between users is beneficial at low SNR. However at high SNR, dedicating the frequency resource is beneficial. Also, any ratio of sharing and dedicating the frequency resource is not beneficial.

With one-bit HARQ feedback, the throughput is improved. For a given SNR, to have strict delay requirements then one has to consider a lower initial transmission rate. The choice of the initial transmission rate can be improved with SNR. Hence, there is a trade-off between delay and the initial transmission rate.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

- In the figure below, throughput (η_1) versus SNR is shown for an open loop system. The black curve is the baseline curve where the frequency resources are dedicated while the proposed approach is the blue curve where there are promising gains at low SNR. Allowing one-bit feedback by means of HARQ, the same behaviour is observed, due to the accumulate nature of HARQ.

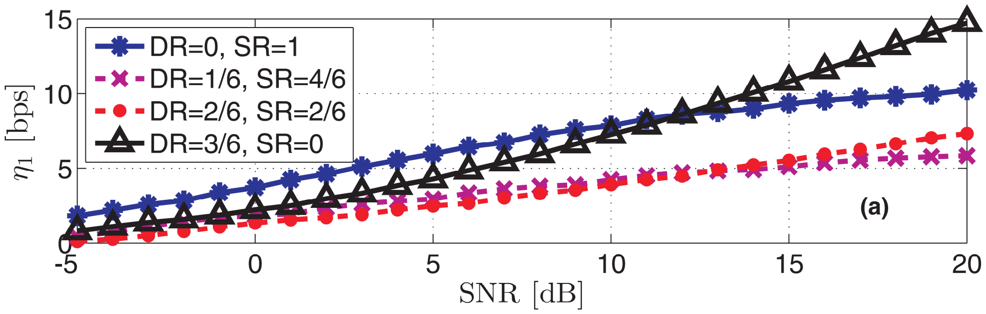


Figure 6-12: Throughput vs. SNR in open loop system captures the trade-off ratio between dedicating resources (DR) and sharing resources (SR)

The delay incurred with one-bit feedback is captured in the figure below for various initial transmission rates for different SNR values. It can be observed that the average delay due to HARQ is lower at high SNR and having lower initial transmission rates. In other words, a strict delay requirement would mean that the initial transmission rate should be lowered; otherwise one has to pay a higher penalty in terms of SNR to have lower delay and higher initial transmission rate.

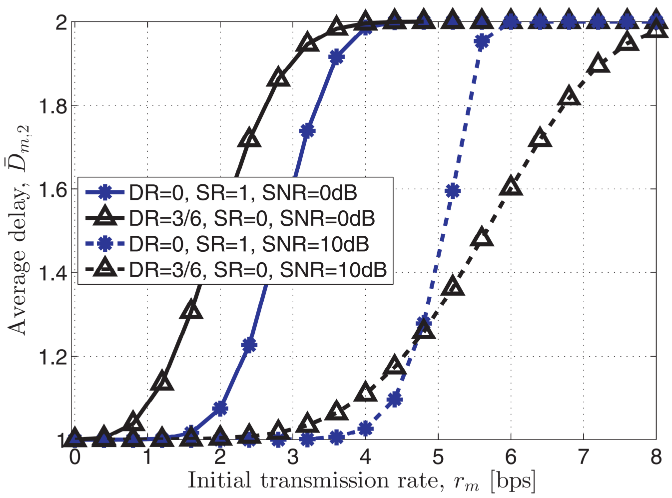


Figure 6-13: Average delay with one-bit feedback

6.1.17 T4.1-TeC7-A1 – Time-sharing approach to interference mitigation using resource auctioning and regret-matching learning

<table>
<tr><th>Main idea</th><th>Requirement and cost</th></tr>
<tr><td>The main idea is to apply the game theoretic approach to multi-tier interference mitigation using a decentralized algorithm. We assume that BSs learn the regrets of possible actions and aim to minimize their average regret over time. The actions taken by BSs represent the partitioning of resources in time and frequency between BSs and used transmit power.</td><td>• BSs exchange the information on channel gains and selected actions periodically
• Low mobility of users (channel assumed to be stationary for multiple TTIs)</td></tr>
<tr><th colspan="2">Advantages and gains</th></tr>
<tr><td colspan="2">• Optimizing the use of resources to minimize the interference and maximize the aggregate rate.
• No need for centralized coordination – optimization performed individually by each BS (based on the knowledge of CSI and decisions taken by other BSs).
• Simulation results in toy scenario:
    o About 15% gain in aggregate throughput comparing to the LTE-A eICIC scheme based on Absolute Blank Subframes (ABS).
    o About 20% gain in small-cells throughput comparing to the LTE-A eICIC scheme based on ABS.</td></tr>
<tr><th colspan="2">Related to trade-off</th></tr>
<tr><td colspan="2">• Complexity vs. performance improvement
• Centralized vs. decentralized</td></tr>
<tr><th colspan="2">How does the TeC relate to the trade-off and how does it affect METIS KPIs?</th></tr>
<tr><td colspan="2">The introduction of interference mitigation based on correlated equilibrium and regret-matching learning increases the overall complexity. The additional resource pattern selection mechanism requires additional computational power at BSs.
When considering the centralized vs. decentralized trade-off, for the proposed decentralized method a periodic exchange of control information is required between the BSs to facilitate the resource use optimization. Two relevant data set are required for the proposed solution: the information on interference caused to neighboring BSs (this can be updated on long time scale – hundreds of ms) and information on selected resource pattern (shorter time scale – ms/tens of ms).
The TeC has the potential to increase throughput, thus addressing METIS KPIs 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.</td></tr>
<tr><th colspan="2">Qualitative results with respect to the trade-off</th></tr>
<tr><td colspan="2">The computational requirements of the proposed solution are high, as computation of utilities for each of the considered strategies is required. However, this can be significantly reduced by applying iterative optimization and simplified utility calculation.
The additional signaling due to the information exchange between BSs will be acceptable (only resource pattern index on short time scale; interference information on long time scale). It is expected that the amount of exchanged control information will be lower than for centralized schemes, such as CoMP.</td></tr>
</table>

6.1.18 T4.1-TeC7-A5 – Self-organization of neighboring femtocell clusters

Main idea	Requirement and cost
The network creates an "Invited Neighbour Subscriber Group" list containing an association between the CSG ID of the own BS and the list of neighbour femtocells, in order to allow camping of users in a controlled way. Femtocells are phase-synchronized through a new beacon signal broadcast by already synchronized BSs with enhanced detection properties, thus avoiding backhaul synchronization protocols.	• Dynamic association between femtocells and potentially invited neighbours to be maintained by a network entity. • Beacon signal must be broadcasted by already synchronized cells in interference-limited UDN scenarios. • Femtocells should periodically track macro beacon signals during DL silence periods. • Femtocell receiver should accumulate the beacon energy over several frames when in low SNR, thus increasing complexity.
Advantages and gains	
• Controlled femtocell camping where dense deployments could lead to signal blockage situations in shared spectrum scenarios. • Over-the-air synchronization mechanism suitable for application of time-domain interference coordination techniques, with no need to upgrade the backhaul in order to support synchronization protocols. • Broadcast nature of the proposed beacon signal leads to very good synchronization success ratios in most practical channels.	
Related to trade-off	
• Long time scale vs. short time scale	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
Operation of this TeC requires femto cells to periodically listen to the macros' beacon signals in order to track synchronization. While doing this, femto cells must switch off their transmitters in order to avoid self-interference, hence deferring downlink traffic with an impact on throughput. The synchronization process should therefore be as quick as possible in order not to impact downlink throughput significantly. However, the quicker the synchronization process, the lower the ability to synchronize in poor signal-to-noise conditions. The minimum time for acquiring synchronization in the proposed TeC is the averaging window length (in ms). Thus there is a trade-off between averaging time and impact on downlink throughput. The resulting self-organized clusters of neighboring femtocells can improve user experienced data rate by firstly allowing the controlled use of otherwise interfering neighbor resources, and secondly enabling advanced inter-cell coordination mechanisms in a distributed way. The TeC would thus point at METIS KPIs of 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.	
Qualitative results with respect to the trade-off	
The 90% synchronization time, and hence the time scale for the synchronization algorithm, appears to depend on the averaging window size and the beacon's SNR. Increasing the window size did not always improve performance as the effect of the enhanced detection properties could be surpassed by the increased search time in a longer window. Relatively small window sizes of 8 – 16 subframes were found to be a good compromise for several conditions.	

Quantitative (graphs, curves, etc.) results with respect to the trade-off
The figure below shows the effect of the window size and the beacon's SNR over the 90% synchronization time. Very poor SNR (-10 dB) leads to long time scales even with large window sizes (up to 516 ms), and moderate SNR (-5 dB) can yield very low synchronization times for small buffers (150 ms with 8 subframes buffer). Impact on DL throughput should therefore be carefully studied in very poor SNR conditions. Most realistic deployments yield beacon's SNR values well above 10 dB, thus leading to very good results with minimal window sizes and little impact on DL traffic.

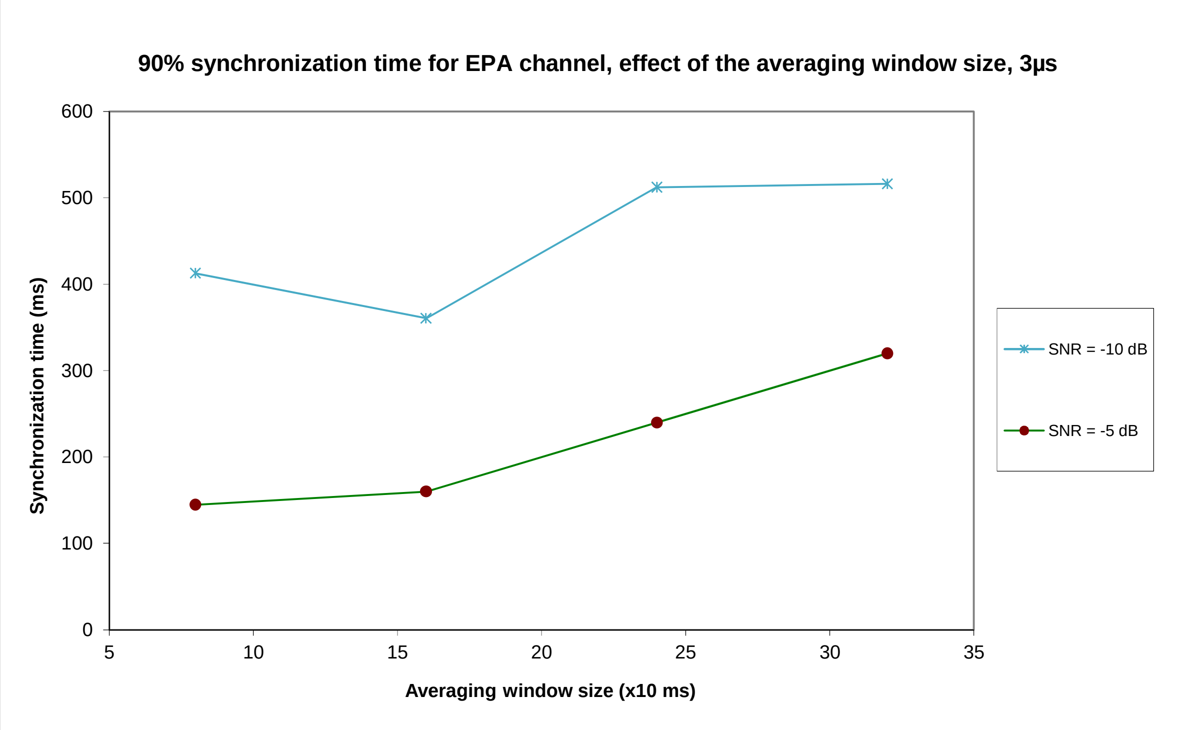


Figure 6-14: 90% synchronization time as a function of the averaging window size for ±3 µs maximum time offset

6.1.19 T4.1-TeC8: Resource allocation scheme for moving relay nodes

Main idea	Requirement and cost
This contribution aims at understanding the impact of CCI and HO parameters on the OP performance of VUEs. The HO parameters are optimized by considering the observed power OP and an acceptable Ping-Pong HO ratio. Then, the overall power OP at VUEs is evaluated by using system level simulations.	• Information about the reference signal received power at the MRN
Advantages and gains	
The power OP of VUEs is significantly lowered in well-isolated vehicles.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.20 T4.1-TeC9 – Dynamic clustering

Main idea	**Requirement and cost**
This technology component aims at creating clusters of nodes among which joint interference coordination may take place. This takes into account the potential dynamics of the nodes that can switch on/off or be on the move. Research will be conducted on clustering schemes that explicitly trade-off the gain from collaboration with the costs of additional signaling.	• This approach requires long term channel statistics (like SNR). • A cooperative technique should be available. • A central processing entity with high computational capabilities is needed.
Advantages and gains	
Unlike conventional schemes, all available resources on different layers can be jointly utilized. Therefore, the system could dynamically identify the available resources of each link taking into account its channel state and capacity. Hence, the coordinated cluster will depend on the user specific case, instead of being fixed by the network topology.	
Related to trade-off	
• Complexity vs. performance improvement • Centralized vs. decentralized • Long time scale vs. short time scale • Energy consumption vs. network capacity and coverage	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
This TeC creates a cluster of cells for each user. Each cluster should collaborate in the transmission to the user. This TeC also allocates power for the transmission to the users. To do this, a central entity is required to perform the optimization, and this entity should have updated SNR values between all cells and users. This increases the complexity as compared to legacy LTE, but, at the same time, it is less complex than other mechanisms that require the knowledge of the channel coefficients. Since only the SNR values are used, this TeC operates in a mid-time scale of around hundreds of TTIs. Moreover, by optimizing the power used in each cell, it reduces the energy consumption and the interference, and yields better network capacity. The TeC aims at METIS KPIs experienced user throughput and energy consumption.	
Qualitative results with respect to the trade-off	
The complexity is not expected to be higher than other centralized multicell techniques. For a given scenario, the TeC reduces the consumed power and, at the same time, increases certain rate objectives, like throughput maximization and fairness.	
Quantitative (graphs, curves, etc.) results with respect to the trade-off	

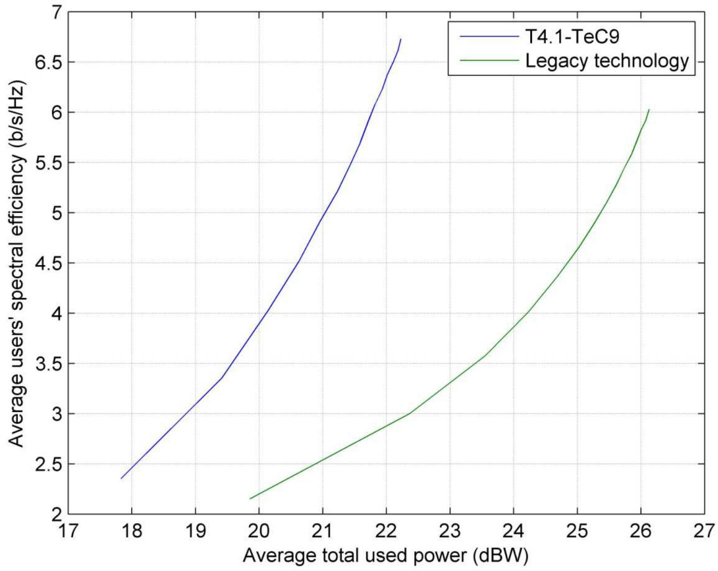


Figure 6-15: Spectrum efficiency by clustering of cells

This figure shows how the users' spectral efficiency increases as more power is consumed by the network. The points were obtained by introducing different number of cells in the network (more cells consume more power).

6.1.21 T4.1-TeC10 – Overlapping super-cells for dynamic effective user scheduling across bands

Main idea	Requirement and cost
This approach proposes to schedule users in different clusters of cells (super-cells). Different carriers shall be allocated to the different clusters of the same cell. By intertwining the connectivity, one can form these super-cells in such a way that every cell edge user finds itself near the centre of a super-cell with favorable situation for eICIC.	• A clustering mechanism should be available. This mechanism should give more than one solution to allow for overlapping super-cells. • Position of users should be known/estimated in the super-cell allocation. • A central processing entity with high computational capabilities is needed.
Advantages and gains	
• Each cell has reuse factor 1. • Users can be allocated to their optimal super-cell, minimizing the number of super-cell-edge users. Moreover, all users can be close to the centre of their super-cell, which is optimum in terms of eICIC.	
Related to trade-off	
• Complexity vs. performance improvement • Information interflow vs. throughput • Energy consumption vs. network capacity and coverage	

How does the TeC relate to the trade-off and how does it affect METIS KPIs?
This TeC designs overlapping clusters of cells that allow users to be served by the optimum cluster according to their position. Coordination among cells within a cluster guarantees that users with worse channel conditions are able to use some of the resources of the cluster in a dedicated manner and thus avoiding intra-cluster interference. The complexity of this TeC lies in the clustering process, where clusters are optimized to use orthogonal resources in overlapping areas. This process can be solved offline. The TeC aims at METIS KPIs experienced user throughput and energy consumption. The improvement in user experienced throughput is at the expense of more information exchange among cells within a cluster. However, a reduction in the energy consumption is expected, due to the fractional frequency reuse scheme applied within clusters.

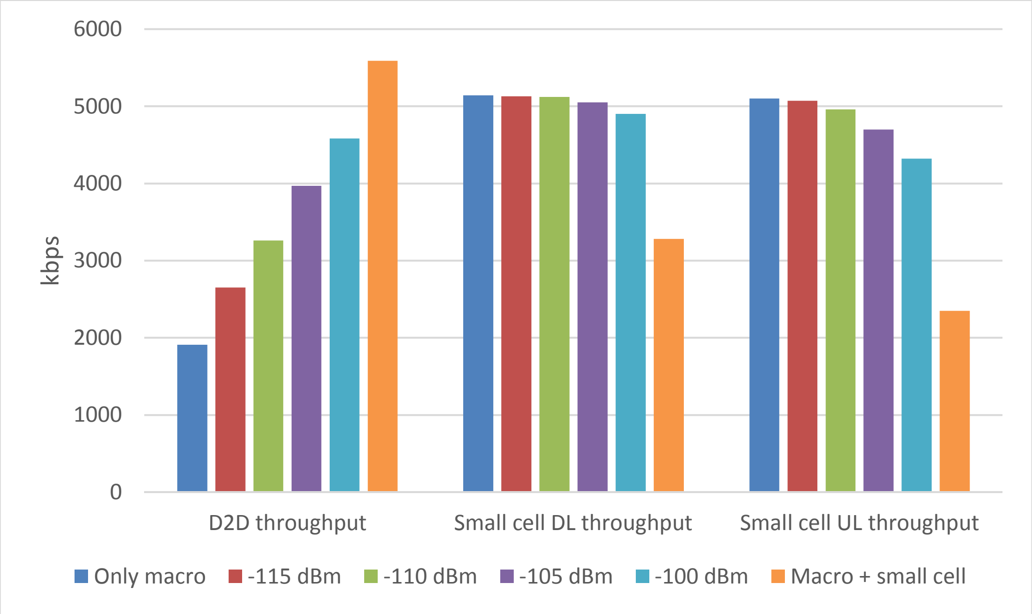
6.1.22 T4.1-TeC12 – Coordinated resource usage in virtual cells

Main idea	Requirement and cost
The main idea is based on the cooperation of cells to improve the throughput of users. Several cells form a cluster which is used as a virtual cell providing service to a mobile device. Additionally, a fountain coding scheme is used for the transmission which enables the mobile device to decode a message based on the received packets from different cells within the virtual cell. In the uplink multiple cells can receive the fountain encoded symbols from the mobile device and jointly decode the message.	• Cooperation between cells • Processing capabilities at mobile device
Advantages and gains	
The approach has two major advantages. Firstly, the use of fountain codes removes the necessity of sending ACKs for every received encoded symbol and eliminating the need for packet retransmissions. The second improvement originates from the spatial gain present in virtual cells which comes with the reception of encoded symbols at different cells.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.23 T4.1-TeC15 – Further enhanced ICIC in D2D enabled HetNets

Main idea	Requirement and cost
UEs of a D2D pair measure during muted subframes of macro BS (that is controlling them). If a strong small cell is not detected nearby, the D2D pair can be allocated resources within those muted resources for their communications, otherwise unmuted resources are used.	• Possibly additional UE measurements of small cells (during muted subframes in macro)
Advantages and gains	
Increased efficiency of resource use	
Related to trade-off	
• Information interflow vs. throughput/mobility enhancement	

How does the TeC relate to the trade-off and how does it affect METIS KPIs?
Allocating more resources for D2D UEs increases the capacity and throughput (both of D2D UEs and those macro cell UEs who can benefit of the resources not anymore used by D2D). Up to a point this causes negligible loss to small cell UEs, but once the D2D users closer to small cells are using the same resources, they start causing interference. So there is a trade-off between D2D capacity gain and interference towards small cells (this decreases UE throughput). This TeC improves UE data rates and NW capacity and thus aims directly at METIS KPI 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.
Qualitative results with respect to the trade-off
Taking additional resources in use for D2D increases the capacity. In order to avoid or limit the interference to the small cells, D2D UEs need to do measurements of small cells. These would be likely part of normal connected mode operation. Reporting the measurement results would cause a small additional overhead, but that would be small compared to the available capacity gain.
Quantitative (graphs, curves, etc.) results with respect to the trade-off
The figure illustrates the gain in mean D2D UE throughput vs. the corresponding loss in mean cellular UE throughput in small cells (due to the increased interference from D2D users). Taking into use the resources reserved for small cell can lead to substantial throughput/capacity gain for D2D UEs. With properly selected safety distance from closest small cell, this can be done with a negligible impact on the small cell UE throughput.  **Figure 6-16: Throughput of D2D UE and small cell users** Figure 6-16 illustrates the gain on mean D2D UE throughput vs. the corresponding loss in mean cellular UE throughput in small cells (due to the increased interference from D2D users). From the figure we can observe that taking into use the resources reserved for small cell can lead to substantial throughput/capacity gain for D2D UEs. With properly selected safety distance, this can be done with negligible impact on small cell throughput.

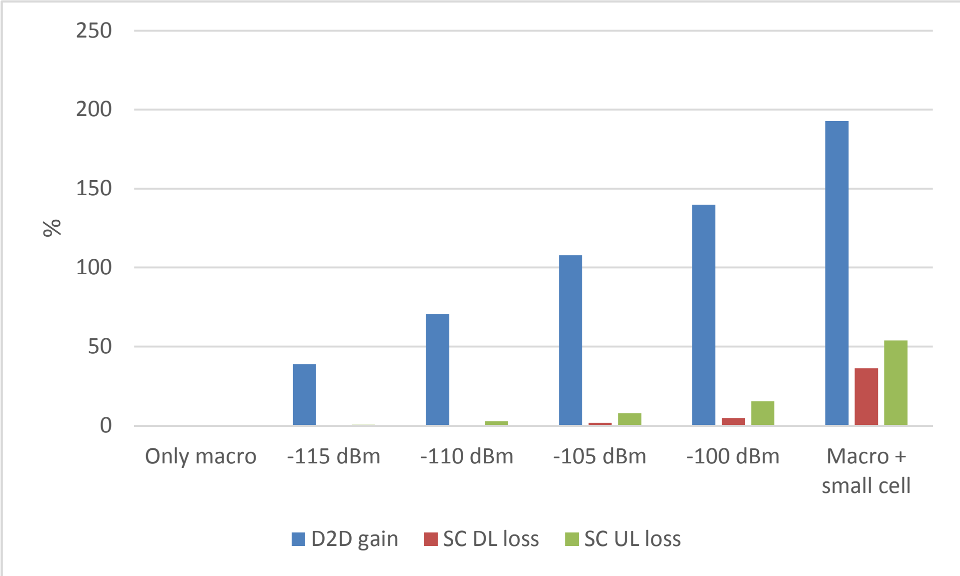


Figure 6-17: Throughput of D2D UE and small cell users

Figure 6-17 further illustrates the trade-off between D2D gain and small cell interference. As seen from the figure we get 39 % gain in D2D throughput with just a 0.2 % loss in small cell DL and only 0.6 % loss in small cell UL. Or 71 % gain in D2D throughput with 0.4 % loss in small cell DL and 2.7 % loss in small cell UL.

6.1.24 T4.2-TeC1 – Optimized distribution scheme for context information

Main idea	Requirement and cost
As a generic approach, we model the design problem as a nested optimization problem. This problem minimizes the CAPEX and OPEX for exploiting the context information in the mobile radio network. The CAPEX and OPEX vary by different context-exploiting mechanisms, which will impact the final achievable gain. Thus, the optimization problem has a set of solutions corresponding to particular context-exploiting mechanisms. The CAPEX and OPEX are determined by the position of the context-aware functionalities, and the required data rate of exchanged information. Based on the state-of-the-art and the recent technical achievement in this project, the maximum data rate of exchanged context information can be derived for certain kinds of context information. We apply the above generic approach to a resource allocation mechanism utilizing location information. For this special use case, optimal distribution schemes are provided, which achieve certain throughput gain at the cost of the increased signaling overhead.	• The CAPEX cost function for the deployment and implementation of the corresponding context-aware functionality • The OPEX cost function to execute the functionality regarding the computational cost and power consumption • The required data rate for exchange of raw and modelled context information and the exchange of control signaling • The achievable gain as a function of the amount of required context information

Advantages and gains
• Achieving the optimal deployment strategy for context-aware systems • Providing general methodology applicable to both centralized and distributed architectures • For location information based resource allocation, balancing the trade-off between throughput gain and signaling overhead.

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.25 T4.2-TeC2 – Context awareness through prediction of next cell

Main idea	**Requirement and cost**
The mobility of users in real life scenarios (ex: In bus, cars or train) are not random but direction oriented. Considered approach proposes schemes to predict next cell for user transition. Based on this context information, load balancing or other RRM schemes are triggered in the predicted next cell.	• Position, velocity and direction (angle) of user is required. • Geometry (carrier-to-interference ratio) of user with respect to the neighbour cells required.
Advantages and gains	
• Consistent prediction even at high velocities. • Timely prediction of next cell allows for proactive triggering of RRM in the predicted next cell. • Improvements in key performance indicators (KPI) namely, reduction in dropping of users, reduction in blocked handover attempts and reduction in blocked access attempts.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

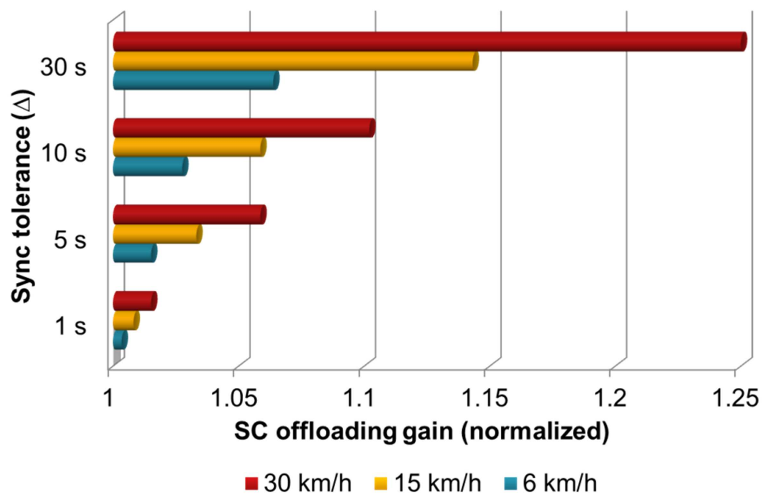
6.1.26 T4.2-TeC4 – Efficient Service to layer mapping and connectivity in UDN

T4.2-TeC4-A1: UE autonomous service connectivity management	
Main idea	**Requirement and cost**
The main idea is to utilize alternate connectivity options in heterogeneous networks, utilizing not only the instantaneous knowledge of a wireless connectivity and the current QoS, but also longer term information on predicted connectivity options.	• Wireless connectivity options (small cells in the proximity), speed, location, preferences, service priorities and battery status is available at UE
Advantages and gains	
Improved offloading, because larger share of traffic will be served when UE is connected to a higher capacity small cell	

T4.2-TeC4-A2: Network-assisted service connectivity management	
Main idea	**Requirement and cost**
The network provides assistance information to the UE to help him decide when to initiate tasks that are delay tolerant but require transfer of large amount of data. This is based on UE indicating its needs in terms of amount of data and delay tolerance.	• Minor additional signalling for exchanging information of pending non-urgent data and scheduling recommendations
Advantages and gains	
• More balanced network load over time, and reduced need for peak network capacity. These benefits are due to being able to schedule large data transfers when there is excess capacity. • Improved UE power efficiency, because UE is served more power efficiently with a larger bandwidth for a shorter time	

T4.2-TeC4-A3: Proactive synchronization for conflict resolution	
Main idea	**Requirement and cost**
To avoid synchronization conflicts proactively, each device can signal to the cloud server about its wireless connectivity characteristics and the estimated synchronization time. As a response, the cloud server can signal back an expected conflict to the devices and asks them for a re-ordering of synchronization tasks (e.g., fast fetching, or postponing)	• Synchronization information per UE and per service (on BS side)
Advantages and gains	
Synchronization problems can be solved proactively in the cloud server applying UE assistance.	

Related to trade-off
• Information interflow vs. throughput/mobility enhancement • Energy consumption vs. network capacity and coverage
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
Timing UE's delay tolerant heavy traffic activity (e.g. backup, SW update, cloud synchronization etc.) so that it takes place when UE is having a high capacity network connection (for example when UE is offloaded to a small cell) improves the power efficiency of the UE and the offloading efficiency in the network. This TeC improves the METIS KPI of 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area by aiming to offload larger portion of the traffic to the small cells.
Qualitative results with respect to the trade-off

There is a trade-off between synchronization delay and offloading, as seen in the results below. Besides that the prediction of UE mobility does cause some overhead though, but if done for a short period of time (up to some tens of seconds) and if the data is not really delay sensitive, the procedure does not need to be too heavy (or fully accurate).
Quantitative (graphs, curves, etc.) results with respect to the trade-off
The figure below illustrates the offloading gain with different synchronization tolerances (ranging from 1 s to 30 s). These results assume that UE has context information indicating the small cell availability for the duration of sync tolerance. The offloading gain is measured in terms of proportion of UEs' traffic served in small cells compared to the reference where UE does not wait for better connection opportunity. From the results it is seen that increased tolerance allows larger portion of the traffic to be offloaded.  **Figure 6-18: Offloading gain with different synchronization tolerances**

6.1.27 T4.2-TeC5-A1 – User Oriented Context-aware vertical handover

Main idea	Requirements and cost
The main idea is an efficient, per-flow, multi-criteria handover scheme, which extends the operation of ANDSF and align its operation with Hotspot 2.0. The HO scheme considers the load of (H)eNBs as well as their backhaul load (by exploiting the Local-ANDSF) and uses the RSS (RSRQ) values for deciding the proper RAT to associate, having service considerations as well. The core decision-making mechanism of the proposed scheme is based on a Fuzzy Logic Controller, which evaluates the available RATs and determines the action.	Requirements: • (L) ANDSF, Hotspot 2.0, IFOM-enabled UEs • Required available parameters: RSSI (RSRQ), UE mobility, (H)eNB, WiFi AP load, Backhaul Load, Service sensitivity to latency Cost: Minimum computational requirements due to the Fuzzy Inference System (FIS) residing on the UE side. This functionality will however affect the battery

consumption.

Advantages and gains

- Up to now the deployed systems are still using simple mechanisms mainly related to the evaluation of the RSS. The proposed mechanism takes into account diverse context-related parameters.
- In addition, in order to acquire the essential contextual information, excessive signalling exchange messages are required. Taking advantage of the evolution of the recent 3GPP standards, the proposed TeC overcomes this handicap.
- Existing approaches do not base their work on realistic business cases, thus, they have to take into consideration too many or too few input parameters for their mechanisms. The proposed scheme offers, though, a holistic business case, feasible and deployable.

Related to trade-off

- Information interflow vs. throughput/mobility enhancement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

With regard to signaling, in order for the UE to acquire the essential information for the RAT evaluation (e.g., (H)eNB load), some extra signaling is required (mainly between the IE and the ANDSF instance that owns this type of information). On the other hand, the mechanism evaluation during the simulations has shown that the overall number of handovers tends to be minimized, resulting in a signaling reduction between the UE and the (H)eNBs/WiFi APs.

As far as the METIS KPIs are concerned, the described mechanism directly aims towards the *10-100x data rate*, as well as the *10-100x number of devices* goals.

Qualitative results with respect to the trade-off

In relation to the information interflow, the signalling increase due to the information acquisition from the UE is balanced by the minimization of the overall number of handovers realised by the UE resulting from the mobility enhancement.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

Currently, an initial collection of results exists primarily with respect to the number of realized handovers, as well as the throughput enhancement experienced by the UE. The results of the proposed mechanism are juxtaposed to the well-known A2A4 RSRQ handover algorithm found in LTE.

Existing results, which describe the reduction of the number of handovers, as well as the throughput (downlink and uplink) enhancement, are given below:

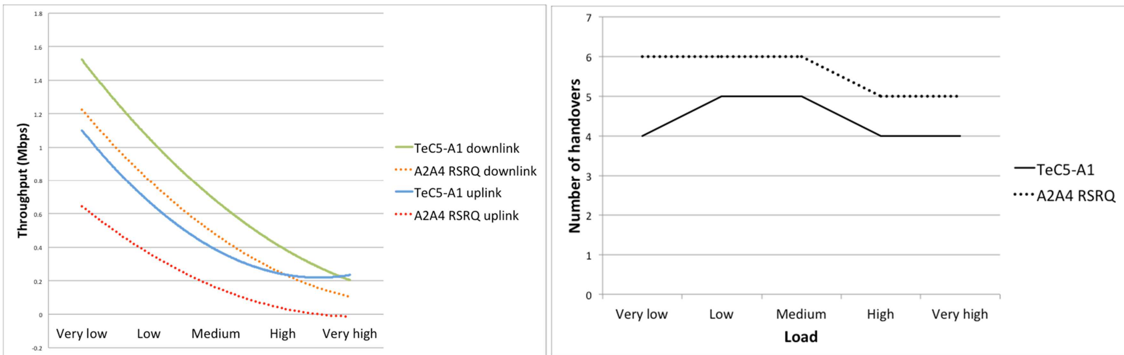


Figure 6-19: (a) Throughput enhancement in uplink and downlink, (b) Handover number reduction

Current quantitative results will be further extended to more sophisticated use case

simulations. The next steps in order to evaluate the described trade-offs is to calculate the signaling overhead that is created during the context information acquisition by the UE and compare this to the signaling reduction due to the handover number minimization.

6.1.28 T4.2-TeC5-A2 – User anchored multi-RAT self-managed load

Main idea	Requirement and cost
BSs broadcast cell load indications through any suitable broadcast control channel. UEs in idle mode would collect cell loads and take them into account along with signal quality levels when performing cell selections and reselections. UEs in connected mode would report neighbour cell loads to the serving node for handover decisions.	• BSs shall broadcast appropriate cell load indications, and UEs should be able to decode them • UEs in idle mode shall incorporate cell loads as additional inputs to the cell (re)selection procedure • UEs in connected mode shall report neighbour cell loads to the serving cell, which would incorporate them as additional inputs for handovers
Advantages and gains	
• No need to exchange signaling information between nodes for load balancing • User-centric approach always interoperable irrespective of the considered RAT • Enables dynamic load balancing procedures at the time scales provided by the measurement reports • Cell load indications could include multiple KPIs including backhaul congestion, processing load and radio resources usage Cell loads could also be estimated by OTA analysis of the air interface signals	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.29 T4.2-TeC7 – Context aware mobility handover optimization using Fuzzy Q-Learning

Main idea	Requirement and cost
The developed Fuzzy Q-Learning scheme applies a limited Exploration/Exploitation Policy (EEP) and first classifies KPI degradations using fuzzy labels. The effectiveness of handover parameter adaptations is learned according to locally observed conditions, where best performance is achieved, if neighboring network nodes collaborate. Further, this approach enables establishing context awareness of location-specific network issues and provides means for self-optimization.	• Regular KPI (connection dropping, handover failure, and ping-pong handover rates) monitoring • If neighbouring network nodes collaborate, exchange of parameter adaptation commands are to be signalled.
Advantages and gains	
• Significant reduction, partly even elimination of mobility-related issues, such as connection drops, handover failures, or ping-pong handovers. • Increased user satisfaction with respect to QoS requirements and link reliability.	

• Efficient from computational point of view
Related to trade-off
• Complexity vs. performance improvement • Information interflow vs. throughput/mobility enhancement
How does the TeC relate to the trade-off and how does it affect METIS KPIs?
The increased complexity of T4.2-TeC7 results from several aspects. The developed fuzzy Q-learning method involves system state classification, fuzzy inference system processing, and requires several iterations until learning converges. Further, learning speed depends on the number of considered parameters and employed classification scheme. Moreover, most promising variants require context information exchange between neighboring network nodes. In particular, mobility-related event counters are collected and exchanged between neighboring network nodes in order to identify those network nodes to which certain events are related (e.g., connection drops, handover (HO) failures, ping-pong HOs). These inferred context information are used for self-tuning system parameters in a cell pair-specific manner and optimizing system performance. The TeC aims at improving link reliability and mobility-related KPIs. Effectively, these improvements can be translated into user throughput gains, since the number of connection drops, HO failures, and unnecessary HOs can be reduced.
Qualitative results with respect to the trade-off
The fuzzy Q-learning based self-optimization schemes have shown to autonomously counteract network performance issues, adapt HO parameter settings according to locally observed conditions, and thus establishing context awareness at network nodes. Fuzzy Q-learning requires only limited network node-specific processing capabilities, since the learning process can be implemented based on look-up tables and arithmetic operations that can be performed using typical multi-purpose processors. Storage size depends on the number of considered parameters and neighbouring network nodes, as well as the KPI update interval. Learning speed depends on the frequency of observed performance issues, employed classification scheme, and considered system parameters and KPIs. The required information exchange among network nodes can be limited to a list of event counters, where the signalling frequency depends on the specified KPI update interval (e.g., in the order of hundreds of milliseconds). In terms of connection drops, reductions of 20-40% can be achieved. In the considered scenario, the number of HO failures was reduced by 80% and regarding ping-pong HOs an improvement of 87.5% was achieved. Overall system performance was improved by 20-22%.
Quantitative (graphs, curves, etc.) results with respect to the trade-off
For each scheme k, the relative improvement of the overall HO KPI is determined as follows: $$\rho_{OPI,k} = w_{CDR}\frac{N_{CDR,REF}-N_{CDR,k}}{N_{CDR,REF}} + w_{HFR}\frac{N_{HFR,REF}-N_{HFR,k}}{N_{HFR,REF}} + w_{CDR}\frac{N_{PHR,REF}-N_{PHR,k}}{N_{PHR,REF}},$$ where $\{w_{CDR}, w_{HFR}, w_{PHR}\}$ represent the weights of the considered KPIs, $\{N_{CDR,REF}, N_{HFR,REF}, N_{PHR,REF}\}$ and $\{N_{CDR,k}, N_{HFR,k}, N_{PHR,k}\}$ denote the number of observed mobility-related issues (connection drops, HO failures, ping-pong HOs), if the reference scheme and the optimization scheme k are applied, respectively. Relative improvements of the investigated schemes are depicted in the figure below, where the four rightmost schemes are based on the developed fuzzy Q-learning method.

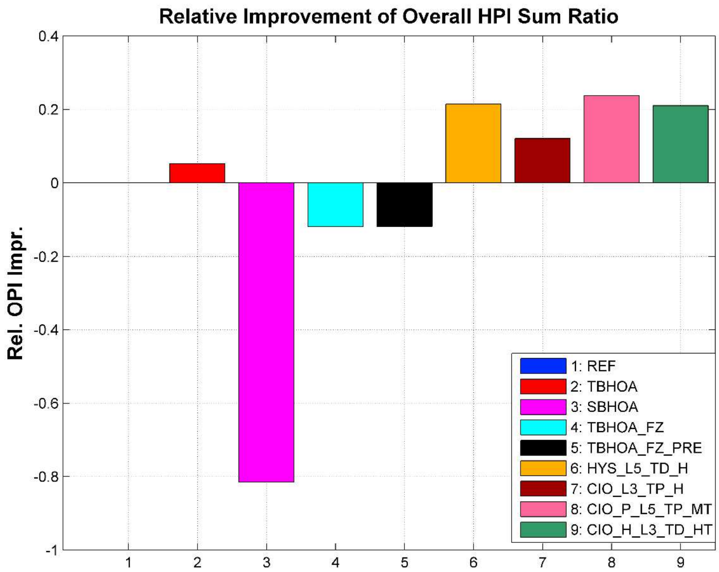


Figure 6-20: Relative improvement of overall HO KPI sum ratio

- KPI-specific results and the number of required iterations for learning process to converge are available.
- So far, given results are based on toy scenario only. However, implementation in TC2 scenario is planned.
- Mapping of mobility-related gains onto user throughput gains is to be done, so that trade-off with respect to complexity vs. throughput gains can be analysed. For example, scheme 8 exhibits highest complexity and outperforms all other schemes. However, learning process requires second highest number of iterations.
- Regarding information flow, it can be stated that schemes considering the exchange of information between network nodes (schemes 7-9) yield good to very good performance. Scheme 6 is able to achieve significant improvements performing only cell sector-specific adaptations at only moderate complexity. However, scheme 6 requires the highest number of iterations.

6.1.30 T4.2-TeC8 – D2D handover schemes for mobility management

T4.2-TeC8-A1: D2D-aware handover management	
Main idea	**Requirement and cost**
Define a new D2D handover condition (signal strength/quality threshold) in addition to the traditional cellular handover condition. Considering two BSs (BS1 and BS2) and two UEs (UE1 and UE2) both are initially controlled by BS1. When UE1 moves towards BS2 coverage and fulfils the cellular handover condition; the network postpones its handover to BS2 until the signal predefined D2D handover condition is fulfilled. Additionally, the handover of UE2 to BS2 is advanced when D2D handover is fulfilled by UE2**.**	• Delayed (or early) HO due to trying to keep the D2D pair in the same cell.
Advantages and gains	

Reduces signalling overhead due to information exchange between two BSs and improves D2D performance in terms of control latency.

T4.2-TeC8-A2: D2D-triggered handover	
Main idea	**Requirement and cost**
Keeping a group of DUEs under different BSs may cause additional delay due to information exchange between controlling BSs. To provide better user experience (in terms of latency) and less control overhead in D2D group communications, DUEs should be clustered in a minimum number of cells or BS. Therefore, when there is a new device wants to join D2D group, it is preferred it is controlled by the same cell or BS already controlling the other DUEs.	• Lower signal quality of the control link if UE is handed over before joining D2D group.
Advantages and gains	
• Reduces signalling overhead • improved D2D performance in terms of control latency	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.31 T4.2-TeC9-A1 – Smart mobility and resource allocation using context information

Main idea	**Requirement and cost**
Smart and joint resource allocation based on prediction of user position and video quality. Our approach makes use of the predicted future rates the user may experience. Such predictions are feasible by exploiting radio maps and the spatial correlation of human mobility patterns. Including such predictions into the resource allocation has a very high potential. Being aware of a user's upcoming rate allows the network to prepare for rate degradation. For instance, if a user approaches the cell edge or a tunnel, the network can increase the wireless rate and request more video packets. Pre-buffering this additional data then provides smooth video streaming while the user is not or only poorly connected.	• User trajectory and rate predictions in the network • Radio resources for signalling context information, storage of radio coverage maps and statistics for user mobility interference and load in a central database
Advantages and gains	
• Predictive Adaptive Streaming (PAS) provides gains for video quality and stream freezing • Increasing the network-wide spectral efficiency	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.32 T4.2-TeC9-A2 – long-term context-aware scheduling for ultra-dense networks

Main idea	Requirement and cost
The proposed component addresses the problem of large user packet delay due to outage or coverage holes in indoor ultra-dense wireless networks. More precisely, the method prioritizes scheduling of the users that are approaching the outage zones. The scheduling decisions are made dynamically in a time-unit basis so the user would be able to be served fairly enough before entering the outage zone.	• Ideal knowledge on user long-term channel assuming ideal estimation of user trajectory in scale of few seconds to few minutes for indoor cases • The uplink traffic is considered due to its more challenging nature
Advantages and gains	
In a legacy system for such an indoor scenario with coverage holes, the user would suffer significant delay if scheduling decisions are made regardless of knowledge of future user trajectory. While utilizing the proposed scheme will significantly reduce the packet delay for the user that is approaching the coverage hole up to 40% by standalone scheduling and to 50% by centralized scheduling with flexible uplink/downlink portioning. On the other hand other users are not affected simply because no significant degradation is observed on their packet delay.	
Related to trade-off	
• Complexity vs. performance improvement • Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
Considering centralized/ standalone radio resource scheduling for indoor UDN, context-awareness is proposed to overcome the problem of large UL/DL packet delay for users that are predicted to be in outage while moving around the network. The scheme increases chance of a user to be scheduled as it approaches the outage zone depending on the upcoming traffic. Knowledge of context information in real system requires extra information flow and computations but leads to performance improvement as mentioned.	
Qualitative results with respect to the trade-off	
Given the outage zones, the moving user would suffer from significant delay if scheduling decisions are made regardless of knowledge of context information (e.g. user trajectory). Utilizing the proposed scheme will significantly reduce the packet delay for the user that is approaching the coverage hole up to 40% assuming standalone scheduling and to 50% by centralized scheduling with flexible uplink/downlink switching. On the other hand other users are not affected simply because no significant degradation is observed.	

6.1.33 T4.2-TeC10 – Signaling for trajectory prediction

Main idea	Requirement and cost
The mobility of users in real life scenarios (ex: In bus, cars or train) are not random but direction oriented. Considered approach proposes schemes to predict next cell for user transition. Based on this context	• Interfaces between neighbouring network nodes are required. • Position, velocity and direction (angle) of user needs to be

<table>
<tr><td>information, load balancing or other RRM schemes are triggered in the predicted next cell. The TeC is concerned with the signaling involved to achieve the prediction schemes and proactive triggering of RRM strategies.</td><td>signalled to the serving BS.
• Geometry (carrier-to-interference ratio) of user with respect to the neighbour cells needs to be signalled to the serving BS.</td></tr>
<tr><td colspan="2">Advantages and gains</td></tr>
<tr><td colspan="2">• Consistent prediction even at high velocities.
• Timely prediction of next cell allows for proactive triggering of RRM in the predicted next cell.
• Improvements in KPIs namely, reduction in dropping of users, reduction in blocked handover attempts and reduction in blocked access attempts.</td></tr>
<tr><td colspan="2">Related to trade-off</td></tr>
<tr><td colspan="2">• Information interflow vs. throughput/mobility enhancement</td></tr>
<tr><td colspan="2">How does the TeC relate to the trade-off and how does it affect METIS KPIs?</td></tr>
<tr><td colspan="2">This TeC investigates signaling required for trajectory prediction and context awareness through prediction of next cell (T4.2-TeC 2). Context information, such as user location, velocity, etc., is regularly sampled, e.g. every 300 ms, for deriving future position estimates. Further, radio signal information (geometry) is measured periodically with respect to the neighbouring BSs. Once the next cell is predicted, a context message needs to be sent to the predicted next cell from serving BS, in order to do resource reservation or to prepare for context aware RRM. The signalling overhead is increased due to the above factors.

The TeC has the potential to increase throughput and enhance mobility and aims at METIS KPI 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.</td></tr>
<tr><td colspan="2">Qualitative results with respect to the trade-off</td></tr>
<tr><td colspan="2">The rate of acquisition of context information such as user location, geometry etc. can be relaxed for users travelling at low velocity. Additional context information about mobility of users (e.g. Diurnal mobility) and road maps will be beneficial to deduce initial and final positions of the user and better prediction of future positions.</td></tr>
</table>

6.1.34 T4.2-TeC11 – Context information building using data mining techniques

Main idea	Requirement and cost
The main idea of the Context information building using data mining techniques TeC relies on the principle that the users tend to have similar behaviours in specific locations during specific time-periods. The TeC aims at capturing the user habits in a decentralized manner and posing the proper requests to the network (H)eNBs). Essentially, given historic observations and a specific time period we attempt to classify user behaviour using a-priori known services (i.e. set S) and their durations (i.e. set D). Thus, we attempt to attribute an observation, a label from	• Slightly increased processing capabilities • Slightly increased storing capabilities

the set SxD. Therefore we will consider extending the technique and accommodate SVM classifiers for the prediction task. In this case, instead of using the whole dataset, we will take decisions using only the support vectors.	

Advantages and gains

- Exploitation of the user habits for better user to RAT/Layer mapping. This will increase also the user capacity and the user experienced throughput.
- Minor computational requirements, which will take place at the UE, in an offline manner.

Related to trade-off

- Complexity vs. performance improvement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

This TeC considers the user behavior and tries to make the appropriate enhancements on traditional network functionalities. For instance, traditional cell selection-reselection and handover schemes exploit user related inputs that concern his current status and measurements. The connection manager exploits the available context (based on the user behavior depending on the location and the time/date) and modifies the UE decisions considering traditional metrics/inputs as well (RSS measurements, policies, service inputs). The context extraction is based on data mining schemes (SVMs) that take place in the user equipment (UE) side in an asynchronous manner.

This TeC aims potentially to contribute to METIS KPI for achieving the goals towards 10 to 100 times higher user data rate, 10 to 100 times higher number of devices, 1000 times higher mobile data volume per area.

Qualitative results with respect to the trade-off

The context extraction procedure is simple because the amount of data will be rather small (i.e., only single user data will be used). Minor computational requirements are expected, which will take place at the UE, in an offline manner. Exploitation of the user habits for better user to RAT/Layer mapping will improve the experienced QoS (in terms of throughput, delay, packet loss, and jitter).

Quantitative (graphs, curves, etc.) results with respect to the trade-off

Initial results have been collected, focusing on the evaluation of the data mining scheme and using network simulator data that have been produced pseudo-randomly for several user categories. Specifically, we generated a large dataset corresponding to the weekly behaviour of 680 individual users, split into three groups, namely day-shift employers, afternoon-shift employers and visitors. The accuracy of the scheme regarding the precise identification of users' habits is presented in the following table.

Indicator	Value
Mean Percentage of Correct Predictions	93.5%
Standard Deviation	0.041
Variance	0.001

Table 6-1: Accuracy of user habits identification

More simulation results will be available in D4.3 capturing also network metrics, apart from the learning ones, provided up to now.

6.1.35 T4.2-TeC12 – Context-based device grouping and signalling

<table>
<tr><th>Main idea</th><th>Requirement and cost</th></tr>
<tr><td>This TeC applies an uplink radio resource coordination scheme for M2M signaling in order to reduce the signaling congestion and network overload probability incurred from integrating M2M communications into the cellular mobile network.

Multiple of M2M devices with similar features are assorted into groups, among which one or more devices are assigned as group representatives (aka group heads) that have higher possibility of signaling requests when an event occurs. The selected group representatives can always be connected to the corresponding BSs using their reserved RACH resources. Upon receiving the message from group representative, the BS will broadcast relevant information in order to prevent the transmission of redundant messages from other group members. Meanwhile, the BS also transmits coordinated uplink information of the RACH and Physical Uplink Shared Channel (PUSCH) assignment for group members which are selected to report their diverse messages, where the RACH and PUSCH resources are successively used following the priority order.</td><td>• Context information for M2M device grouping
• Uplink and downlink signaling channels
• D2D communications between group member and representative (optional)</td></tr>
<tr><th colspan="2">Advantages and gains</th></tr>
<tr><td colspan="2">• Congestion probability incurred from massive M2M devices triggered simultaneously can be significantly reduced, where unnecessary retransmissions are effectively avoided.
• The amount of network signalling can be greatly reduced with an efficient internal scheduling mechanism.
• The proposed RACH coordination scheme can optimize the efficiency of using available RACH resources and, meanwhile, can greatly improve the efficiency of management in performing a service for a multiple of M2M devices.</td></tr>
<tr><th colspan="2">Related to trade-off</th></tr>
<tr><td colspan="2">• Information interflow vs. throughput/mobility enhancement</td></tr>
<tr><th colspan="2">How does the TeC relate to the trade-off and how does it affect METIS KPIs?</th></tr>
<tr><td colspan="2">This TeC aims to reduce the signaling overhead for MMC traffic and mitigate the possible congestion in the signaling channel. Hence it has a direct impact on the signaling overhead in the uplink and downlink channel. The redundant messages from content-related devices are prevented. The diverse messages from the content-related devices will be transmitted in RACH and PUSCH channel in a coordinated manner.
Two METIS KPIs, i.e. the network capacity regarding the number of connected devices and latency of the mobile services, are enhanced by this TeC. By mitigating the signaling congestion, the network can support more devices with the link level capacity. It will also reduce the overall signaling delay caused by the signaling congestion.</td></tr>
<tr><th colspan="2">Qualitative results with respect to the trade-off</th></tr>
</table>

Depending on the traffic load in the network and the correlation between the signaling messages, the TeC provides different level of improvement in the signaling channel. In order to coordinate the RACH access between difference devices, additional cost in broadcast channel is required. Furthermore, context information which is utilized to group the devices is necessary for the TeC.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

In addition to the results shown in section 3.4, simulation results in Figure 6-21 show that the proposed mechanism yields significant reduction in the signalling congestion probability, especially when the number of deployed M2M devices goes extremely large.

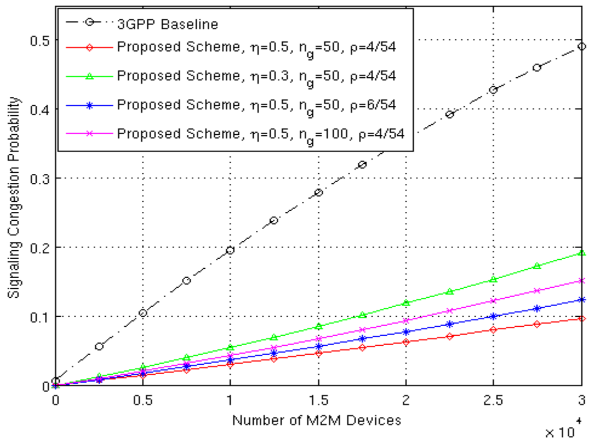


Figure 6-21: Signal congestion probability in RACH

Furthermore, the simulation plots also reveal several major factors influencing the network performance of the proposed mechanism, namely the percentage of redundant messages *η*, the group size n_g, and the number of dedicated resources reserved for the group representatives *ρ*. It can be generally observed that, the proposed mechanism has higher gain when there is a higher percentage of redundant messages. The performance is also impacted by the properly assigned amount of dedicated resources for the group representatives in line with the group size.

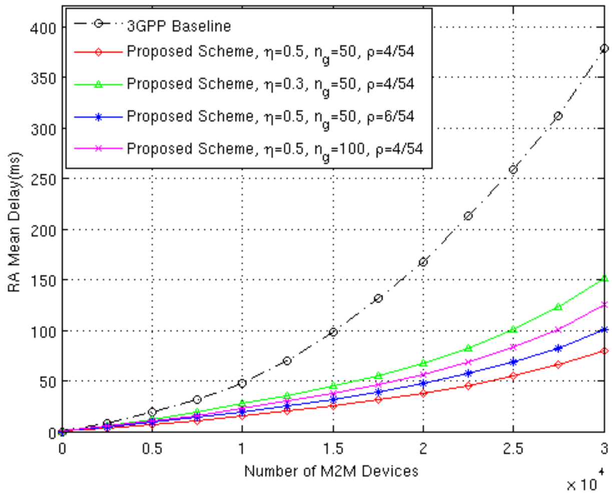


Figure 6-22: Mean delay in RACH

6.1.36 T4.2-TeC13-A1 – Small cell mobility enhancements in multicarrier and mmW small cell network - Network assisted small cell discovery

Main idea	Requirement and cost
UE gets assistance information from the network to target the search of small cells. This consists of radio fingerprints of the coverage carrier (e.g. RSRP of neighboring macro cells) that indicate a small cell location or a HO region. UE reports to network when there is a fingerprint match and based on this the network can configure targeted measurements (on specific carrier) for finding the corresponding small cell.	• Gathering and signalling the radio fingerprint information
Advantages and gains	
Reduced UE power consumption, because UE will spend less time blindly measuring small cell carriers	

6.1.37 T4.2-TeC13-A2 – Small cell mobility enhancements in multicarrier and mmW small cell network - Small cell discovery in mmW small cell networks

Main idea	Requirement and cost
Assuming mmW band BS is serving also a low-frequency carrier, UE detects whether there is LOS link between UE and BS based on measurements of the low frequency signal. This is used for controlling the measurements on mmW carrier. Detection of LOS is based on received signal characteristics (CIR, RMS delay spread, RSSI) on the low-frequency carrier where the UE is primarily connected	• Detection of LOS link based on measuring and analysing and classifying signal characteristics.
Advantages and gains	
Reduced UE power consumption, because UE will spend less time blindly measuring on mmW carriers	
Related to trade-off	
• Energy consumption vs. network capacity and coverage • Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
Configuring UE with a set of fingerprints that correspond to small cell locations on other frequencies allows UE to limit its inter-frequency measurements (for finding inter-frequency small cells). UE can measure only when it is within or near the coverage of a small cell thus avoiding unnecessary measurements. This decreases UE's energy consumption. When there are a large number of carriers to search, the search also becomes on average faster because the UE can directly search the correct carrier. The trade-off is the additional signaling overhead from collecting, storing and signaling the fingerprints. Another trade-off here is the effective small cell coverage (and capacity as this affects how well the offloading opportunities offered by small cells are utilized) because the signaling overhead (or energy consumption) can be reduced by sacrificing the accuracy of the coverage mapping. This TeC helps improving device battery lifetime. Seen the other way, performing the small	

cell search more power efficiently and faster allows UE to find more offloading opportunities without compromising power consumption.

Qualitative results with respect to the trade-off

The benefit in terms of energy consumption from searching inter-frequency cells is shown in the figure below. The proportion of this search of the total device power consumption depends on how often the UE searches as well as the number of carriers it searches. With current LTE-A assumptions inter-frequency measurements mean 5 ms of measurements every 40 or 80 ms [ref. TS 36.133], which would mean approx. 6-12 % power consumption compared to having receiver on continuously. Measuring more than one inter-frequency carrier does not consume more power in LTE-A, but slows down the search proportionally to the number of carriers.

Collecting and storing the fingerprints should not be a very large effort for the network. This could happen as part of SON functionalities. However, signalling the fingerprints to the UE does cause some overhead. One fingerprint (PCI and RSRP measurement for strongest macro cells and a matching range) takes in the order of 50-60 bits, if we assume 3 strongest macro cells are considered. Indicating 20 FPs would mean around one kilobit of data. Overhead of receiving this by the UE consumes significantly less energy (likely < 1 ms of reception) than searching multiple carriers for long periods of time (several minutes or even hours).

Quantitative (graphs, curves, etc.) results with respect to the trade-off.

The figure below illustrates the trade-off between power consumption of small cell search (inter-frequency measurements) and fingerprint coverage. This is given for different numbers of FPs per small cell location. Different FP matching ranges have been considered to obtain the different trade-off curves between fingerprint coverage and measurement power saving.

Increasing the number of fingerprints per small cell enables more accurate mapping of small cell coverage and thus a better trade-off between fingerprint coverage and power saving. However, in practice the number of fingerprints is limited due to the signalling overhead from transmitting those to the UE.

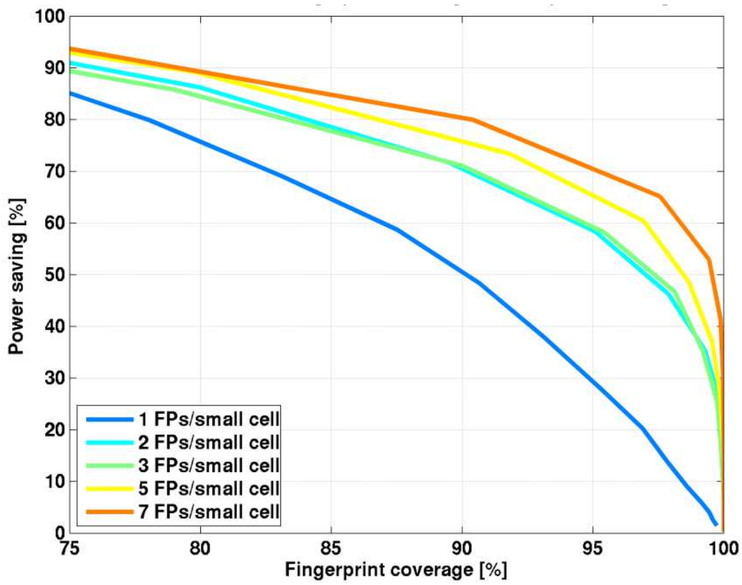


Figure 6-23: Trade-off between fingerprint coverage and power saving

6.1.38 T4.2-TeC14 – Context-aware smart devices and RATs/layers mapping

Main idea	Requirement and cost
Proposed approach requires a centralized RRM mechanism where context information is collected and exploited at BS for a more efficient mapping of RATs/layers. Regarding different types of services and devices, different KPIs are under inspection for the optimization problem in order to reasonably optimize the network performance.	• CSI information, user profile, service requirement, geo-location information and available battery energy level need to be available at BS. • Increased signalling.
Advantages and gains	
• Improved resource utilization by context-aware RRM algorithm w.r.t. different KPIs, e.g. number of established links, system capacity. • Improved service reliability w.r.t. user satisfaction ratio. • Improved battery life for lower power devices	
Related to trade-off	
• Complexity vs. performance improvement • Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
By taking context information into account for smart RATs mapping, the complexity of RRM algorithm increases. Meanwhile, information interflow is required to provide context information as inputs to smart RRM algorithm. Therefore, signaling overhead is increased in order to provide these information, e.g. CSI, user service requirement, user or service priority information. The TeC has the potential to increase number of supported users and thus aims directly at METIS KPI 10 to 100 times number of devices.	
Qualitative results with respect to the trade-off	
The more context information is available at BS, the smarter RRM algorithm can be exploited, and the better system performance can be achieved. A smart algorithm should consider various types of information when it maps resource to devices.	
Quantitative (graphs, curves, etc.) results with respect to the trade-off	

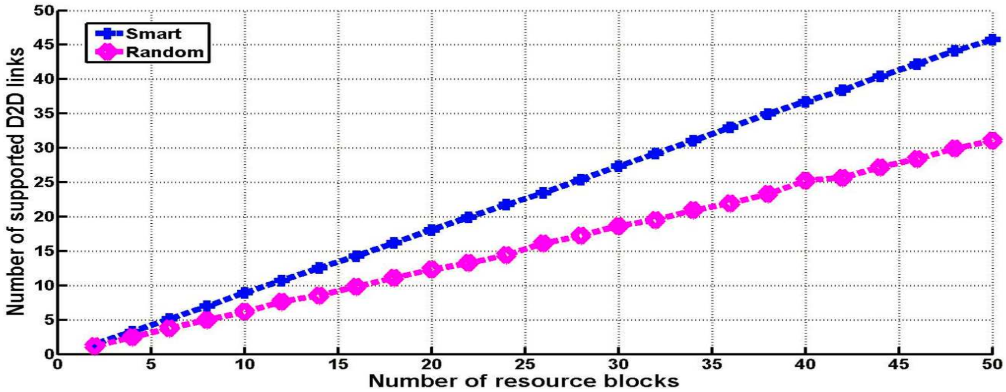


Figure 6-24: System performance in terms of number of supported D2D users

The figure shows the system performance between our smart RRM algorithm and a baseline algorithm for D2D communications. Our smart RRM algorithm exploits context information, e.g. CSI information to allocate resource for D2D links. As a comparison, a random resource allocation scheme is inspected where no context information is taken into account and therefore BS randomly allocates resource for D2D links. As it can be seen from this figure, our smart algorithm outperforms the random scheme with an approximate relative performance gain of 50%. The signaling scheme to provide CSI information for smart algorithm is a trade-off between information interflow vs. system performance.

6.1.39 T4.2-TeC16 – Scalable solution for MMC with SCMA

Main idea	Required Information and cost
Multiple access is achieved by generating multiple codebooks, one for each user. The system can be overloaded where the number of multiplexed layers is more than the spreading factor. SCMA is scalable to support different levels of overloading by adjusting the code word length (or spreading factor) and the number of non-zero elements in the code word. A contention-based mechanism is employed such that machines can transmit data in pre-configured resources that comprise of time, frequency, codebooks and pilots. The size of the resources and transmission parameters can be changed based on traffic demands. Data transmission is done without the dynamic request/grant procedure.	• SCMA contention access region(s) and associated SCMA parameters such as codebooks used

Advantages and gains
• Scalability to support varying traffic loading • Support of massive connectivity through overloading • Low signaling overhead • Reduced transmission latency

Related to trade-off
• Complexity vs. performance improvement • Information interflow vs. throughput/mobility enhancement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?
The SCMA multi-user detector used in the TeC is non-linear. However, due to the sparsity of code words, the complexity of the receiver can be significantly reduced. Therefore, the SCMA system is able to tolerate more collisions between users and meanwhile maintain the good quality of detection with affordable complexity. In general, the dynamic signaling overhead of radio resource allocation will be increased as the number of devices increases. In order to reduce/eliminate the dynamic request and grant overhead of supporting a large number of devices, a grant-free contention-based SCMA solution is proposed with pre-configured resources that comprise of time, frequency, codebooks and pilots with low signaling overhead. Another aspect is the timeliness of data delivery (latency) vs. number of supported devices. The number of supported devices decreases as the delay constraint becomes tighter. The ability for a contention-based SCMA mechanism to support more users is advantageous for traffic with tighter delay requirements. This TeC has the potential to increase the number of devices supported in a cell. The objective is to achieve the METIS goal of providing connectivity for 300,000 devices within one cell.
Qualitative results with respect to the trade-off
The signaling required for the TeC is small. The information is mainly related to configuration of the contention SCMA which can be communicated when device enters the system and when there are configuration changes. Configuration parameters include information of the SCMA contention region(s), codebooks and MCS settings. There is no dynamic request and grant signaling for data transmission. Therefore, as number of device increases, the dynamic signaling overhead is not increased. The collision probability can be controlled by adjusting the SCMA contention regions and codebooks overloading. Complexity of SCMA receiver is more than a linear receiver. Sparsity of SCMA code words helps to significantly reduce the complexity of detection compared to full MLD receiver for traditional non-sparse spreading sequences as in CDMA.
Quantitative (graphs, curves, etc.) results with respect to the trade-off
For trade-off between latency and number of devices, the following table provides the performance of the proposed contention-based SCMA solution compared to an *evolved* legacy system with contention-based OFDMA. The number of devices that can be supported per MHz of bandwidth when the average packet drop rate is 1% is shown below. Two scenarios are considered: no retransmission and with at least 1 retransmission. In the case of no retransmission, this applies to traffic that has very low latency requirements such that packets are dropped if any retransmission is carried out. Given an ACK feedback delay of 4 ms assumed in the simulation, any traffic air-link latency requirement of less than or equal to 4 ms falls into this case. For the case of at least 1 retransmission, the random back off window is set such that a device is guaranteed to retransmit at least once. In this simulation, the window size is set to 16ms. This means that the worst case delay for the first retransmission is (4 + 16) = 20ms. It is assumed, therefore, the delay constraint of this case is 20ms.

	No Retransmission	At least 1 Retransmission
Contention OFDMA	121,875	611,719
Contention SCMA	328,125	1,082,813
Gain	169%	77%

Table 6-2: Number of devices that can be supported per MHz

It can be seen that a contention-based SCMA system can support 169% more devices than a contention-based OFDMA system when no retransmission is possible under a tight delay constraint.

6.1.40 T4.2-TeC17 – Downlink Multi-User SCMA for Mobility-Robust and High-Data Rate MN-M

Main idea	Required Information and cost
Open-loop downlink multiple access is achieved by pairing multiple SCMA codebooks, one or a few for each user. The MU-SCMA system can be overloaded where the number of multiplexed layers is more than the size of a code word dimension. Users are paired without need for the knowledge of their CSI. The downlink transmit power is shared among paired layers according to the users channel quality indicator (CQI) and their long-term traffic rates. As MU-SCMA is a non-orthogonal codebook-based multiplexing scheme, a nonlinear receiver such as MPA is used at each user node to detect the intended layers. SCMA is scalable to support different levels of overloading, complexity, and spectral efficiency by adjusting the code word length and the number of non-zero elements in the code word.	• Information of paired users in terms of SCMA layer to user mapping and power allocation to layers/users • Codebook size and code rate of each layer

Advantages and gains
• Support of high-rate wireless communication links. It improves cell throughput and coverage of a network. • Support of mobility-robust communication links as MU-SCMA does not need users' CSI for pairing. • Downlink user multiplexing without need for full channel knowledge; Negligible CSI feedback overhead • Scalability to trade-off between throughput gain and complexity • More than 50% cell throughput gain for certain scenarios

Related to trade-off
• Complexity vs. performance improvement • Long time scale vs. short time scale • Information interflow vs. throughput/mobility enhancement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?
Open-loop downlink multiple-access is achieved by pairing multiple SCMA layers over same time-frequency resources. The downlink multi-user SCMA (MU-SCMA) system can be overloaded where the number of multiplexed layers is more than the size of a code word dimension. As a result, the overall network throughput and coverage are improved. Users are paired without need for the knowledge of their full CSI. Therefore, the system can avoid high signaling overhead of CSI feedback as in legacy multiple-access schemes such as MU-MIMO. The downlink transmit power is shared among paired layers just according to the users channel quality indicator (CQI) and their long-term traffic rates. MU-SCMA is robust to channel variations so it can be well fitted to high mobility users with high traffic demands. As MU-SCMA is a non-orthogonal codebook-based multiplexing scheme, a nonlinear receiver is used at each user node to detect the intended layers. The complexity of receiver is more than a linear receiver but sparsity of SCMA code words helps to significantly reduce the complexity of detection. In addition, SCMA is scalable to support different levels of overloading, complexity, and spectral efficiency by adjusting the code word length and the number of non-zero elements in the code word.
Qualitative results with respect to the trade-off
Advantages of MU-SCMA: • High throughput and coverage for heavily loaded networks (TC6) • High throughput for high speed scenarios (TC8). It improves the robustness of the system to mobility. • No need for any full or partial knowledge of users' channels. It saves the system the overhead of CSI feedback as already existed in closed-loop multiple access schemes such as MU-MIMO. • More flexible link-adaptation by changing the number of allocated layers to a user as well as layer allocated power and rates. It can help to better utilize the capacity of the channel. • SCMA spreading can provide more robust link-adaptation due to spreading of interference across a wider bandwidth. This feature is important especially with a lightly loaded system where the resource utilization is low and fast interference fluctuation reduces the rate of the network. • More robust and smoother handover by sharing SCMA codebooks across neighbouring cells. • Scalability to support different levels of overloading, complexity, and spectral efficiency by adjusting the code word length and the number of non-zero elements in code words. Price to enable MU-SCMA: • Complexity of SCMA receiver is more than a linear receiver. • Sparsity of SCMA code words helps to significantly reduce the complexity of detection compared to full MLD receiver for traditional non-sparse spreading sequences as in CDMA.
Quantitative (graphs, curves, etc.) results with respect to the trade-off
• The cell throughput and coverage gain of MU-SCMA over OFDMA can be more than 30% regardless of the user speed. • For a given coverage rate requirement, MU-MIMO can improve the aggregate cell throughput of a network by 50%. • In **Error! Reference source not found.**, the complexity of nonlinear MU-SCMA MPA receiver with 2 receive antennas is compared with a 2x2 MMSE receiver. The overall complexity of SCMA nonlinear receiver is about 4 times more than a typical linear

MIMO detector.

6.1.41 T4.2- TeC18: UE vs Network driven handover

Related to trade-off

- Information interflow vs. throughput/mobility enhancement

How does the TeC relate to the trade-off and how does it affect METIS KPIs?

T4.2-TeC18 investigates pros and cons of two alternative options of handovers: UE autonomous and network controlled. Such analysis is based on LTE-A numbering in dense small cells deployment. From the point of view of 5G system design it is important to check those two options in order to suggest more suitable one. TeC influence METIS latency and energy objectives by suggesting solution which minimizes handover interruption time as well as information exchange and optimal signaling flow. Considered scenario involves all use cases with moving user equipment.

Qualitative results with respect to the trade-off

Investigations suggest qualitative results in terms of optimal information flow related to considered handover options. Also initial proposal for the use cases and give-and-takes of both options is given.

For NW controlled HO smaller interruption time is expected for active users (i.e. with data in the buffer). Additionally this scheme exploits better the cloud architecture, allows easier enforcing of network policy, admission control before HO and contention-free RACH. To minimize the HO interruption time we suggest RACH-less handover and avoiding system information reading.

UE autonomous one allows for shorter HO reaction time, i.e. imply less HO failures due to long measurements and X2-like transmissions, it enables more frequent consecutive HO e.g. for high mobility UEs. To minimize the HO interruption time we suggest faster information reading and 1-step RACH

Quantitative (graphs, curves, etc.) results with respect to the trade-off

Investigation in T4.2-TeC18 provides qualitative analysis of handover interruption time for UE autonomous and NW controlled handovers. Assumed input values are related to different signaling/information flows related to investigated alternative options. Numerical values for both options are available

KPI	Network/ inter-site	UE/ inter-site
Interruption time UL	1.25 ms	6.5 ms*
Interruption DL	4.5 ms	6.0 ms*
HO reaction time	11.25 ms**	0.5 ms
Packet forwarding time	11.75 ms	15.75 ms*
Total handover time	27.5 ms	21.25 ms
Max extra packet latency	5.0 ms***	6.5 ms*

Table 6-3: Analysis of handover interruption time for UE autonomous and NW controlled handovers

* = impacted by long BSI reading time, ** = impacted by long HO decision making time, *** = equal to X2 latency

6.1.42 T4.3-TeC1-A1 – New management interface between the operator and the service provider

Main idea	Requirement and cost
A new management interface between the SPs and the MNO will bind the requirements of the SP much stronger to the MNO in order to provide near real-time, event-based adaption of the network settings to services. • SP gets access to the SON-based functionalities of the RAN through controlling interface (itf-c) in order to optimize the parts of the network affecting its customers. Monitoring interface (itf-m) allows SP to check the status of the network and to observe the settings done by the MNO and control interfaces for access to the parameter settings of the SON. • Context-based optimization processes obtains all necessary information from the RAN and interacts with SON mechanisms through itf-ci. In this case, SPs can get access to the context-based processing A novel Access Control Function checks the messages from the service provider. The interfaces support extensions for scalability.	• Depending on the agreement between the SP and the MNO, different physical and logical parts of the network are allowed to be modified, i.e., interface access points can be different, and, thus, should be specified.
Advantages and gains	
• Enable better planning, performance, and interworking of external SPs with network operators through new network management interface • In-time distribution of specific knowledge to the right points in the network • Develop network management interface between services located in the cloud as well as distributed in the network infrastructure • Cooperation among different networks to support one or multiple services • Better recognition and exposition of network status with respect to services • Exchange of context information among network functions	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.43 T4.3-TeC1- A2: New management interfaces for information exchange and action enforcement

Main idea	Requirement and cost
This TeC analysis the WP4 TeCs from information exchange requirement point of view in order to identify the appropriate parameters which will be required to be measured, stored, or communicated in the scope of the WP4 TeCs. Further, extensions to interfaces required to support the WP4 TeCs deployment and interworking in the network will be proposed.	• This TeC aims at addressing interface requirements posed by all TeCs within WP4. • The objective is to complete a detailed investigation of existing interfaces, measurements and information flows so as to

Information items under consideration include: • Profile information related to network elements static information, user preferences and service requirements • Measurements performed by certain devices (e.g. UE) • Policies, constraints and actions which have been identified as appropriate for managing the network elements and resources and achieve performance enhancements. Consideration of logical (proposed) and physical entities in LTE HetNet context.	minimise required modifications. • Extensions and new interfaces will be proposed where it is required.
Advantages and gains	
• Exchange of context information among network functions and entities • Communication of policies and actions enforced to the various network entities • Harmonised approach for proposing interfaces extensions and definition or development based on the analysis of the WP4 TeCs • Providing feedback from management point of view to specific TeCs regarding information exchange and interworking.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.44 T4.3-TeC2 – Clustering Toolbox

Main idea	Requirement and cost
This mechanism proposes the grouping of nodes into concise clusters for better node coordination. This procedure may be performed in both static and moving nodes, with different criteria in each case, and result into stable groups. The outcome of this mechanism can be considered as input in tasks where small groups of nodes are being considered.	• Position information • Mobility information for moving nodes • Signal measurements from neighbouring nodes to measure similarity
Advantages and gains	
• Improved coordination of nodes • Efficient grouping of nodes • Formation of compact groups that facilitate the exchange of time critical information without network assistance (e.g., vehicular safety)	
Related to trade-off	
• Complexity vs. performance improvement • Centralized vs. decentralized	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	

This TeC investigates clustering mechanisms for proper coordination of nodes in mobile networks, where the number of devices is constantly changing. Different schemes are evaluated and compared in order to examine their potential application and impact on nodes' coordination schemes. Such mechanisms focus on the grouping of nodes into smaller clusters and grouping nodes with high similarity in the same cluster. Means of similarity, in mobile networking environments are a) high signal quality from neighboring nodes and also b) close distance among nodes can be viewed as potential aspects.

This TeC aims potentially to contribute to METIS KPI for achieving the goals towards 10 to 100 times higher number of devices, 10 time longer battery life, and 5 times reduced E2E latency.

Qualitative results with respect to the trade-off

The application of clustering mechanisms increases the number of messages that are exchanged for clusters formation but it is expected to facilitate the network for i) efficient spectrum allocation inside smaller groups of nodes, ii) energy saving from Access Point activation/deactivation and iii) efficient support of moving nodes.

Quantitative (graphs, curves, etc.) results with respect to the trade-off

For this TeC the clustering output has been evaluated for a certain topology (TC3 Shopping Mall environment), where femtocells are deployed. The signal quality received among femtocells is considered as a common characteristic, and to be more precise we define a connectivity threshold. Simulation results indicate that a high/strict connectivity threshold is appropriate when we need to group nodes for interference management while a low/relaxed threshold can be chosen for RRM problems (i.e., handover, power control, etc.). For the evaluation of the formed clusters, modularity is used (i.e., a general metric that measures the quality of the clustering output).

Sensitivity Threshold	Algorithm family	Algorithm	No Clusters	Modularity
-80dB	Data mining	k-Means	4	0.497
		HAC	4	0.476
	Sensor	3hBAC	7	0.432
	Graph theory	MCL	6	0.172
-90dB	Data mining	k-Means	3	0.216
		HAC	3	0.185
	Sensor	3hBAC	2	0.273
	Graph theory	MCL	2	0.267

Table 6-4: Simulation analysis for the TC3 with different sensitivity thresholds

Thereinafter, clustering mechanisms for moving networks (e.g., vehicular environment) will be tested and evaluated.

6.1.45 T4.3-TeC3-A2 – Dynamic Nomadic Node Selection for Backhaul Optimization

Main idea	Requirement and cost
This method proposes a mechanism for identification of the optimum serving nomadic cell based on the backhaul link quality, where due to low alleviation and severe fading characteristics the backhaul can easily be the bottleneck on the end-to-end link. The proposed scheme exploits the diversity via the	• A set of NNs are available in a target region. There is overlaying macro cell coverage for the backhaul connections. • The long-term channel quality information is available for the

availability of multiple NNs in a confined region, e.g., parking lot.	backhaul links of NNs. The coarse NN selection requires long-term measurements and, thus, the signalling overhead is expected to not high.
Advantages and gains	
• Clearly improved backhaul link quality; thus, clear end-to-end performance gains • Clearly reduced experienced amount of fading (AoF) on the backhaul link • Enables dynamic network-planning on-the-fly • Enables flexible service provisioning on-demand	
Related to trade-off	
• Information interflow vs. throughput/mobility enhancement	
How does the TeC relate to the trade-off and how does it affect METIS KPIs?	
The TeC analyzes two schemes to enhance the backhaul link between BS and nomadic nodes (NNs). The NN selection is based on signal-to-interference plus-noise ratio (SINR) on the backhaul link. On this basis, the coarse NN selection takes into account long-term channel quality measurements based on shadowing, whereas, the optimal selection relies on the short-term channel quality measurements based on both shadowing and multi-path fading. The achievable SINR and end-to-end data rate gains are higher in case of optimal NN selection compared to those of coarse NN selection. Nevertheless, the signalling overhead incurred by the optimal NN selection due to frequent channel quality information exchange is higher than the one pertaining to the coarse NN selection. Accordingly, there is a trade-off between the achievable gains and the required information interflow. In particular, when the backhaul link is the bottleneck on the two-hop communication assuming inband half-duplex relaying operation, the TeC achieves clear end-to-end rate gains. Therefore, the TeC contributes to the METIS goals of 10 to 100 times higher user data rate and 1000 times higher mobile data volume per area.	
Qualitative results with respect to the trade-off	
The required reporting overhead due to channel quality information is low in case of the coarse NN selection. As the NNs are not moving (or of low mobility) during the operation, long-term measurements shall be sufficient to attain the promised gains. In dynamic environments, e.g., possible shadowing by parked trucks in legally permitted regions, the update rate and thus signaling overhead would increase.	
Quantitative (graphs, curves, etc.) results with respect to the trade-off	
The TeC demonstrates improvements through the NN selection schemes on the backhaul link SINR and data rate relative to random NN selection (see **Figure** 6-25 below as an example).	

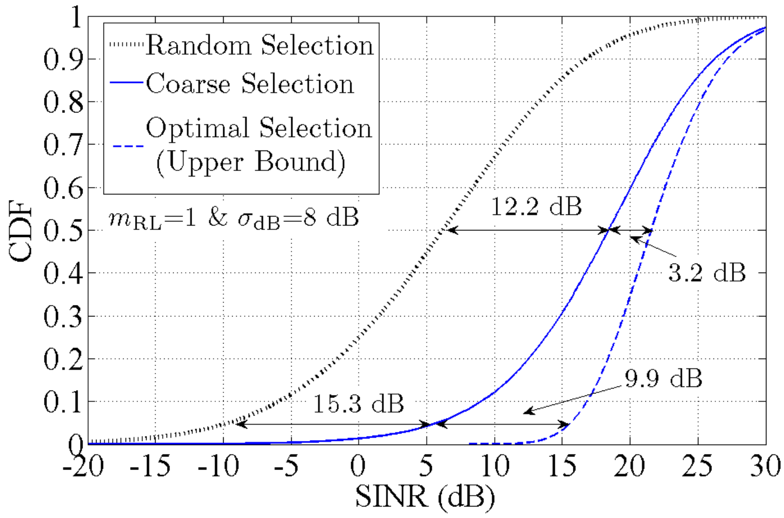


Figure **6-25: SINR improvement on the backhaul link via NN selection**

6.1.46 T4.3-TeC4-A1 – Activation and deactivation of nomadic cells

Main idea	Requirement and cost
The main idea is to model the decision of activation and deactivation as an optimization problem where the objective could be energy consumption of the whole network, user battery life or network load, etc. The constraints of the optimizing problem lie in two aspects: 1. UEs and RNs must be connected to the network 2. The available bandwidth at each node must be sufficient to support the minimum rate requirement of the UEs and the forward data rate of the RNs. Certain relaxation techniques are needed to efficiently solve the optimization problem since both objectives and constraints are non-convex.	• CSI or the estimation of the channel quality between BS-UE, BS-RN and RN-UE; • Location and availability of the candidate nomadic RNs; • UE data requirement ; • Available network bandwidth;

Advantages and gains
• Capacity and coverage enhancement • Network energy saving and longer UE battery life. • Load balancing

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.

6.1.47 T4.3-TeC4-A2 – Activation and Deactivation of small cells in UDN

<table>
<tr><th>Main idea</th><th>Requirement and cost</th></tr>
<tr><td>This method proposes a scheme for the dynamic activation or de-activation of small cells exploiting UL/DL capacity and topological information that user equipment and small cells provide to macro cells, assessing the current network status in terms of coverage, quality of service, and blocking probability.</td><td>De-activated small cells should periodically “wake-up” and broadcast their presence.
The communication cost/delay between different SCs and MCs.</td></tr>
<tr><th colspan="2">Advantages and gains</th></tr>
<tr><td colspan="2">Improved allocation of network resources and network capacity in a UDN.
Enhanced quality of service and lower blocking probability.
The dynamic activation/de-activation of small cells affects/facilitates the operation of other management tasks e.g., interference, scheduling, energy management.</td></tr>
<tr><th colspan="2">Related to trade-off</th></tr>
<tr><td colspan="2">Energy consumption vs. network capacity and coverage</td></tr>
<tr><th colspan="2">How does the TeC relate to the trade-off and how does it affect METIS KPIs?</th></tr>
<tr><td colspan="2">This TeC is proposed to provide network connectivity at all desired locations and sufficient bandwidth to satisfy clients’ communication needs, eliminating the wasting of network and energy resources. The dynamic activation or de-activation of small cells (SC) exploits UL/DL capacity and topological information that user equipment and small cells provide to macro cells, assessing the current network status e.g., in terms of coverage, quality of service, and blocking probability.
The de-activation of a SC is triggered when there is too high coverage overlap, while the capacity usage ratio is too low. In the case of low coverage, low CQI or even high blocking probability the activation of one or more SCs is checked attempting to provide more resources wherever it is necessary. Both actions are followed by the handover of a set of UEs.
This TeC aims potentially to contribute to METIS KPI for achieving the goals 10 to 100 times higher number of devices, 1000 times higher mobile data volume per area and 10 time longer battery life.</td></tr>
<tr><th colspan="2">Qualitative results with respect to the trade-off</th></tr>
<tr><td colspan="2">For the de-activation case, performance enhancement when comparing to the initial active SCs, is expected for energy consumption in the network side. The goal is to avoid the underutilisation of provided resources (capacity, coverage), taking into account service and traffic requirements. On the other hand, in the case of SCs re-activation coverage and capacity are increased, with the respective energy cost, especially for the network side.</td></tr>
<tr><th colspan="2">Quantitative (graphs, curves, etc.) results with respect to the trade-off</th></tr>
<tr><td colspan="2">Some initial results for a simple UDN topology are available. In the specific scenario user-experienced throughput depends on the specific location of SCs (e.g., after several de-activations (8 HeNBs) the throughput is reduced; in all other cases throughput remains the same or even increased), while no packets are dropped in all cases (0% packet loss ratio). A decrease in the monitored delay is also observed.</td></tr>
</table>

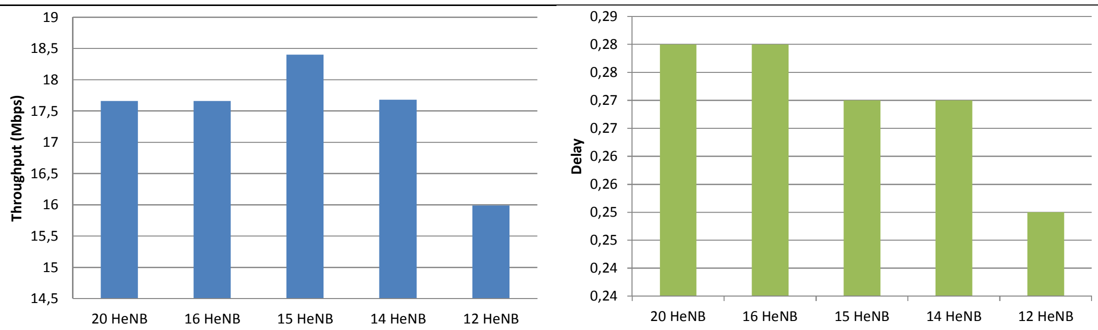


Figure 6-26: (a) Downlink and Uplink throughput for SC de-activation, (b) Downlink and Uplink delay for SC de-activation

The evaluation of this mechanism is ongoing and it is also planned to address more complex scenarios for both activation and de-activation cases, by measuring also energy consumption for both UE and HeNBs during transmission and reception phases. The results of the conducted experiments will be provided in the context of D4.3.

6.1.48 T4.3-TeC5 – Self-management enabled by central database for energy savings in the Phantom Cell Concept (PCC)

Main idea	Requirement and cost
Database-aided energy savings mechanism in HetNet deployments where small cells are deployed in a clustered fashion to reflect the need for localized capacity in public urban hotspots. Each macro cell is equipped with a database storing information about the channel quality of the small cells connected to it by a backhaul link. This way, small cells can be put to sleep to save energy, and UEs can still connect to the small cells in a macro-assisted way even when they are not discoverable via the air interface.	• Periodic reports of UE geographic location information required • Necessity to equip each macro cell with a database • Database training to obtain enough channel quality (e.g. SNR) values

Advantages and gains

- Achievable energy savings of up to 30% in case of high network load and up to 85% in low network utilization scenarios.
- No negative influence on the achievable UE throughput, some throughput gains observed in low network utilization cases due to the reduced level of interference in the small cell network.

Related to trade-off

- Energy consumption vs. network capacity and coverage

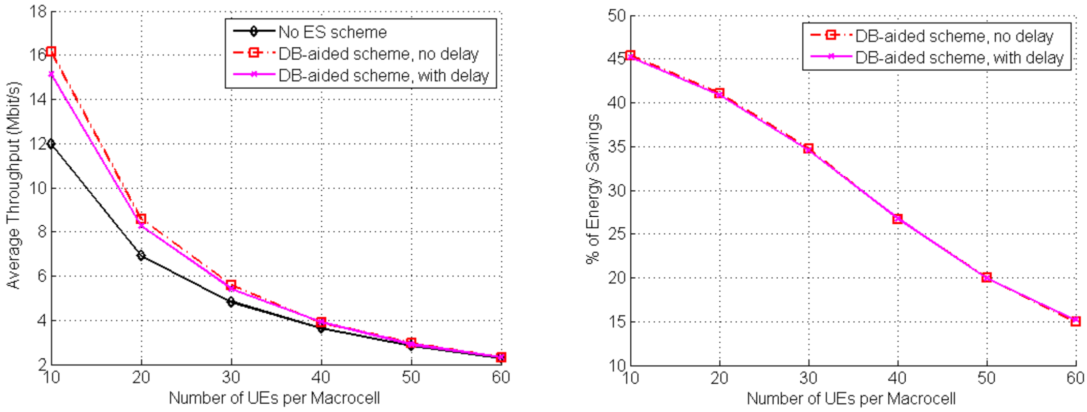
How does the TeC relate to the trade-off and how does it affect METIS KPIs?

While the considered database-aided scheme helps to reduce the energy consumption of the system by turning off unused small cells, it is subject to some connection setup delays which can potentially reduce the average achievable user throughput and increasing the time to deliver packets, hence reducing the global capacity of the system.

On the other hand, the fact of turning off a large number of small cells can also reduce the global level of interference in the system, potentially enabling small cells to transmit with a better modulation and coding scheme, thereby compensating the signaling delays and increasing the achievable throughput, in line with METIS KPI of 10 to 100 times higher user data rate.

Qualitative results with respect to the trade-off
System-level simulations implementing the delays due to connection procedures have been performed. It is indicated that the introduction of signalling delays has no noticeable influence on the system performance.

Quantitative (graphs, curves, etc.) results with respect to the trade-off
System-level simulations implementing calculated delays for the considered database-aided scheme yield to a slight degradation to the throughput performance, when comparing the case where the delays are ignored, as observed on Figure 6-27-a. However, this performance degradation is marginal, and the performance obtained by the delay-aware scheme is still higher than the performance obtained when no energy savings scheme is implemented. Figure 6-27-b indicates that the introduction of delay does not have any impact on the achievable energy savings by the system.



(a) (b)

Figure **6-27: (a) Throughput performance and (b) achievable energy savings by the database (DB)-aided energy savings scheme when considering and ignoring signalling delays**

6.1.49 T4.3-TeC6 – Framework for control/user plane design with over-the-air signaling for UDN

Main idea	Requirement and cost
Proposed solution focus on optimization of overall system performance and efficiency through solutions encompassing both cellular transmission and network-facilitated D2D. Performance is evaluated based on the different level of centralization.	• Channel state and buffer information needs to be additionally signalled from small cells to Macro in case of centralized approach • CSI information and RRM decisions are delayed by small cells-Macro-small cells

	transmission for the D2D transmission
Advantages and gains	
• Small cell backhaul may be realized via Ethernet / any third-party provider, as only user plane is handled over this (assuming data is moderately delay-tolerant) • Infrastructure cost required for reliable backhaul link for control plane is alleviated.	

The performance analysis of this TeC focuses on METIS KPIs. A specific investigation of the trade-offs presented in this document is not planed.