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Abstract:

This deliverable provides the conclusions of the project by pointing out the key scientific results achieved in ONE5G. It further provides a set of recommendations that we have drawn from those results for the next phase 5G New Radio. Additionally, the deliverable contains a summary of the exploitation and dissemination activities and the impact of the project.
In agreement with the project officer we have combined the two project deliverables D6.2 and D1.2 into a single document as they are both covering the same period (the whole project) and are covering complementary areas: the overview of the results and their exploitation and dissemination, the conclusions of the project and its socio-economic impact.

Keywords:

5G, New Radio, Air Interface, MBB, MMC, mMTC, MCC, URLLC, V2X, PHY, mMIMO, NOMA, MAC, RRM, Megacities, Underserved Areas

Executive Summary (HPM)

As specified by the project technical annex this document is issued by work package 1 and work package 6. It constitutes the final report as required by the grant agreement of the project. Its purpose is to provide the reader a global overview about the work done during the project without having the intention to provide details. Those are covered within the respective deliverables of the technical work packages to be found at the project's web site [ONE5G_web] ([D2.1], [D2.2], [D2.3], [D3.1], [D3.2], [D4.1], [D4.2], [D5.1], [D5.2]) and within the references given in those.
The document starts with an outline of the scientific core results of the project and the recommendations we have drawn from those.
We have structured this part following the structure of the project itself (System requirements Integration and evaluation, end-to-end (E2E) multi-service performance evaluation, multi-antenna access and link enhancement and lessons learnt from the Proof of Concept (PoC) activities).
The project has provided significant outcomes building on the characterization of E2E performance through Key Quality Indicators (KQIs), like new scheduling schemes and an innovative traffic-steering mechanism. Multiple solutions have been proposed to minimize power consumption, while another set of solutions aims to facilitate the implementation of 5G key technologies (Massive MIMO or mMIMO) and architectures (CRAN). Then we have proposed enablers to improve the coexistence of multiple services, such as NOMA and Grant-Free Access. In total, the analysis in the technical work packages WP3 and WP4 has led to recommendations on 80 features.
Throughout the project's lifetime, the needs and specificities from verticals have been kept in mind, up to the PoCs and techno-economic assessment.
Subsequently, we present the achievements of the project related to exploitation, dissemination, standardization and innovation.
Finally, we close this deliverable with the assessment of the impact of the project and provide the conclusions.

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
ADC	Analog-Digital Converter
AP	Access Point
AR	Augmented Reality
ARPU	Average Revenue Per User
ARQ	Automatic Repeat Request
BBU	Base Band Unit
BLER	Block Error Rate
BS	Base Station
BW	Bandwidth
BWP	Band Width Part
BLC	Bit Level Combining
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CC	Component Carrier
CC-BLC	Chase-Combining Bit Level Combining
CC-SLC	Chase-Combining Symbol Level Combining
CDRS	Compensated Discovery Reference Signal
CLI	Cross-Link Interference
CN	Core Network
CoMP	Coordinated Multi Point
CP	Control Plane
CQI	Channel Quality Indicator
CRAN	Centralized Radio Access Network
CS	Compressed Sensing
CLI	Cross Link Interference
CSI	Channel State Information
CSIT	Channel State Information at the Transmitter
CU	Central Unit
D2D	Device to device
DC	Dual Connectivity
DCI	Downlink Control Information
DES	Discrete Event Simulation
DL	Downlink
DMRS	Demodulation Reference Signal
DMTC	DRS Measurement Timing Configuration
DnF	Decode and Forward

DPS	Dynamic Point Selection
DRAN	Distributed Radio Access Network
DRB	Data Radio Bearers
DRS	Discovery Reference Signal
DRX	Discontinuous Reception
DU	Distributed Unit
DVS	Device Virtualization Server
E2E	End-to-end
eMBB	Enhanced Mobile Broadband
eNB	Enhanced NodeB
E-PDB	Extended Packet Delay Budget
ESN	Emergency Service Network
FDD	Frequency Division Duplex
FEC	Forward-Error Correction
FLC	Fuzzy Logic Controller
FoF	Factories of the Future
FPC	Fractional Power Control
FTP	File Transfer Protocol
GB	Grant-Based
GF	Grant-Free
gNB	Base station in NR
GUI	Graphical User Interface
GUL	Grant-less Uplink
H2020	Horizon 2020
HARQ	Hybrid Automatic Repeat Request
HD	High Definition
HetNet	Heterogeneous Network
HLS	Higher Layer Split
HOF	Handover Failure
HOM	Handover Margin
HTTP	Hyper-Text Transfer Protocol
IAB	Integrated Access and Backhaul
IIoT	Industrial Internet of Things
IDMA	Interleave-Division Multiple-Access
IM	Interference Mitigation
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
KPI	Key Performance Indicator
KQI	Key Quality Indicator
LAA	Licensed Assisted Access

LBT	Listen Before Talk
LLS	Lower Layer Split
LMMSE	Linear Minimum Mean Square Error
LO	Local Oscillator
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution – Advanced
MAC	Medium Access Control
MAS	Multi-cell Aggregation Scheduler
MBB	Mobile Broadband
MC	Multi-Connectivity
MCA	Multi-Channel Access
MCC	Mission Critical Communications
MCS	Modulation and Coding Scheme
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MLaaS	Machine Learning as a Service
mMIMO	Massive Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
mMTC	Massive Machine Type Communications
MTC	Machine Type Communications
MTD	Machine Type Communication Device
MOS	Mean Opinion Score
MSE	Mean Squared Error
MRT	Maximum Ratio Transmission
MU-MIMO	Multi-User MIMO
NARX	Nonlinear Autoregressive Exogenous Models
NFV	Network Function Virtualization
NF-NCJT	None-Fully-Overlap Non-Coherent Joint Transmission
NOCA	Non-Orthogonal Coded Access
NOMA	Non-Orthogonal Multiple-Access
NORA	Non-Orthogonal Random Access
NR	New Radio
NSA	Non-Standalone
NWDAF	Network Data Analytics Function
OAI	Open Air Interface
OAM	Operations, Administration and Management
OFDM	Orthogonal Frequency Division Multiplexing
OoB	Out of Band
OPEX	Operational expenditure
OS	Operating System
PDCCH	Physical Downlink Control Channel

PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PIC	Parallel Interference Cancellation
PLL	Phase Locked Loop
PoC	Proof of Concept
PRB	Physical Resource Block
PSCM	Probalistically Shaped Coded Modulation
PT-RS	Phase Tracking Reference Signal
QnF	Quantize and Forward
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RE	Resource Element
REST	Representational State Transfer
RF	Radio Frequency
RFNoC	RF Network on Chip
RLC	Radio Link Control
RLF	Radio Link Failure
RR/RC	
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal
RSRP	reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSU	Roadside Unit
RX	Receiver
RZF-CI	Regularized Zero Forcing with Controlled Interference
SA	Standalone
SB	Sub-Band
SDAP	Service Data Application Protocol
SDO	Standards Development Organization
SDR	Software-Defined Radio
SE	Spectral Efficiency
SFN	Single Frequency Network
SI	System Information
SINR	Signal to Interference plus Noise Ratio

SIP	Session Initiation Protocol
SLC	Symbol Level Combining
SLS	System-Level Simulator
SNR	Signal-to-Noise Ratio
SoTA	State of the Art
SUL	Scheduled Uplink
SVC	Service Vertical Coordinator
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time-Division Multiple-Access
TeC	Technical Component
TLS	Transport Layer Security
TR	Technical Report
TRP	TX/RX Point
TS	Technical Specification
TTI	Time Transmission Interval
TX	Transmitter
UCA	Uniform Circular Array
UP	User plane
UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra-High Definition
UL	Uplink
UMa	Urban Macro (3GPP channel model)
URLLC	Ultra-Reliable Low-Latency Communications
USRP	Universal Software Radio Peripheral
UTRAN	Universal Terrestrial Radio Access Network
V2X	Vehicle-to-X
VR	Virtual Reality
VRU	Vulnerable Road User
WB	Wide-Band
WP	Work Package
WRC	World Radiocommunications Conference

1 Introduction

1.1 Objective of the document

This document constitutes the final report of ONE5G. It collects and summarizes the essence of the work done in ONE5G with respect to both the project-wide objectives and on a per work package level. Here, we collect the major recommendations being developed during the project and the key lessons learnt related to the enhancement of multi-antenna access and link level technologies as well as the optimization of end-to-end performance for multiple services. The consideration is for the two main environments – the dense mega-city as well as the underserved areas.
WP1 and WP6 – the originators of this document – have no resources allocated to actual research. So, the material provided in the following is completely based on the work being done in the technical work packages of the project as reported in their respective deliverables. This document is to provide an overview of those outcomes without having the intention to go into detail. Those are to be found within the respective deliverables of the other work packages.

1.2 Structure of the document

The document starts with an outline of the results in relation to the project's objectives and the scientific results of the project and the recommendations we have drawn from those. This is followed by the presentation of the achievements of the project related to exploitation, dissemination, standardization and innovation. We end this deliverable with outlining the impact of the project and the conclusions of the action.

2 Works towards the objectives of ONE5G

In the following we list the overall objectives of the project. For each objective we shortly summarize the activities of the project having contributed to meeting these objectives. .

Objective 1: To propose the necessary 5G extensions, from the performance and cost perspectives, in order to address the two selected scenarios ("Megacities" and "Underserved Areas").

By the starting date of the project, the first phase of 5G New radio (NR) had been mostly defined and stabilized within 3GPP. The "early drop" of Release 15 in December 2017 froze the technical specification for the lower layers [TS 38.214 ED]. Consequently, ONE5G mainly bases the work on this first version of 5G and developed techniques and optimization schemes to upgrade this first version.
The project has worked towards enabling 5G to address a wide variety of deployment types, from the very dense and crowded urban environments, to remote and scarcely populated areas. As a first step towards this objective, we have defined two deployment scenarios ("Megacities" and "Underserved Areas"), to serve as a reference for the technical developments in the project [D2.1] stressing the main challenges, such as the density and heterogeneity of nodes, devices and services to be addressed in Megacities, and the tight constraints regarding long coverage distances, energy efficiency , potentially harsh operational conditions, or cost efficiency to enable economically viable deployments for Underserved Areas.
To further shape the work of the technical work packages 3, 4 and 5, and to have a common base, we have agreed on a set of use cases covering both scenarios and the three service categories being in consideration by 3GPP: enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low-Latency Communications (URLLC) and massive Machine-Type Communications (mMTC). We have described those use cases both in terms of general functionality and in terms of Key Performance Indicators (KPIs). The "5G extensions" developed in the project are therefore being assessed with respect to these KPIs. The "Megacities" scenario, involving a wider variety of services, and as a result more constraints, has been more frequently addressed than the "Underserved Areas" scenario, and several technologies will be applicable to both scenarios, even if assessed in a Megacity context.
As cost is also a very crucial aspect both for the deployment and the operation of a 5G system, especially for the "Underserved Areas" scenario, a techno-economic analysis has been led on a selection of use cases (see objective 5).

Related to the scenario "Megacities", a set of technical enablers have been studied and developed within the project focusing on various crucial aspects as follows (actual details are covered in subsequent sections and within the public deliverables of the project):

- for achieving higher throughput and connection densities:
    - **Massive Multiple-Input Multiple-Output (mMIMO)** represents a main asset to increase throughput. Several topics are addressed in WP4, such as beam management and optimized array formats. Performance of massive MIMO systems relies on the availability of Channel State Information (CSI), so efficient CSI acquisition and feedback schemes have been investigated as well, using for example compressed sensing approaches. Innovations have been developed to facilitate the deployment of mMIMO systems, such as optimized array formats to adjust to the evolution of traffic throughout time. Hybrid arrays have also been proposed, leading to improved energy efficiency when dynamically adapted to varying traffic conditions.
    - **Centralized Radio Access Network (CRAN)** allows for efficiently supporting cooperative transmissions and can accommodate a huge number of devices with very high data rates. So CRAN (but also DRAN, i.e. Distributed Radio Access Networks) is another major area addressed in the project, with the development of physical layer techniques and procedures improving the reliability and efficiency of CSI acquisition and feedback.
    - **Non-Orthogonal Multiple Access (NOMA)** techniques allow to improve performance at the cell edge for eMBB users and is also crucial to sustain the growing connection density, especially for mMTC services.
- The concurrent support of highly differing services (e.g. with different traffic characteristics and QoS requirements) is another crucial target of 5G. So, the project investigates **efficient resource allocation strategies and scheduling schemes,** such as pre-emptive scheduling to manage the urgency of URLLC transmission while preserving the transmission quality for the eMBB traffic. Grant-free access is investigated to allow for reduced signaling efforts and for reduced latencies. **Dynamic multi-connectivity management** has been developed in WP3, to optimize the use of resources.
- Prediction mechanisms have been proposed, to forecast and avoid service degradation due to network overload (such as a prediction algorithm relying on information gathered from social events to forecast load increases and perform load-balancing).

Related to the scenario "Underserved Areas", the project also develops solutions addressing its inherent challenges as follows:

- Specific **beamforming techniques**, designed in WP4, allow for higher intercell distances (reducing the cost of the network) thanks to improved coverage, with new precoding schemes and array formats. Coverage extension is also enabled with device-to-device (D2D) relaying schemes, defined in WP3.
- Cost is an important constraint in areas characterized by a low Average Revenue Per User (ARPU). The previously mentioned beamforming techniques targeting an improved coverage will enable the use of **wireless backhaul**, a cheaper option than a wired backhaul for deployment with severe cost constraints. **Standalone operation in unlicensed frequency band**, investigated in WP3, could be of interest to produce cost-efficient solutions for specific cases of "Underserved Areas", such as hot spots. Time-variant **optimal network slicing** will allow adjusting to price levels.
- Energy efficiency is a main design target for various topics being studied in the project. Optimal **RRC state handling** and use of **discontinuous reception (DRX)** improve energy efficiency by minimizing the unnecessary usage of wide bandwidths, or by selecting the appropriate configuration of inactivity timer settings. Other solutions consider the optimization of the **functional split between central and distributed units** and the **resource allocation in CRAN/DRAN**, to adjust the number of activated computational units, and minimize the energy consumption. Energy efficiency is strongly related to the **implementation**, therefore different front-end options are also compared in terms of energy consumption.
- Techniques minimizing the required overhead for **channel state estimation**, and enhancements for **grant-free access** (e.g. collision avoidance and/or handling) are investigated to improve cost and energy efficiency.

More specifics on the above listed advancements are following in the subsequent sections and within the public deliverables of the project.

Objective 2: To build consensus on new features that must be considered in the various releases of 5G, and to provide technical recommendations for moving 5G towards "5G advanced (pro)". These technology elements will solve identified issues, not yet sufficiently covered by 5G at this point in time. The ONE5G outcomes will be fed towards 3GPP in releases 16 and 17 (i.e. RAN phase 2 and phase 3 work items).

During the first quarter of the project, 3GPP already reached a rather stable initial version of 5G NR, providing the fundamental characteristics of the radio stack, though, with a strong focus on eMBB. So, subsequent submissions from 3GPP (to releases 16 and 17) require including further enhancements to enable new use cases being covered by the service categories URLLC and mMTC. Even for eMBB further enhancements

are to be expected beyond what has been decided so far. ONE5G covers all three service categories.
To have a clear view on the baseline to be enhanced, Project Manager and Technical Manager have prepared a rather extensive summary of the outcomes of the 5G NR related study item of 3GPP, as well as of the relevant projects in the framework of phase 1 of H2020 [D2.1]. Additionally, we have identified the relevant future study/work items from 3GPP being relevant landing zones for ONE5G.
As outlined in objective 2, ONE5G's target has not only been to develop enhancements to be fed towards 3GPP, but in addition to develop a common view on those. For achieving this, the technical work packages have convened virtually via regular phone calls to discuss ongoing investigations. Synergetic partner activities have been identified and connected (either as they are solving the same problem by different means or as one activity might support the other e.g. by providing relevant inputs). As a follow-up those sub-groups have been developing their technologies in a coherent manner. This kind of activity was even enhanced during the regular face-to-face meetings. These synergies have led to joint publications.
To be of relevance someone needs to adopt the agreements being made within 3GPP. To name an example, the simulation activities conducted in ONE5G followed the guidelines being provided by 3GPP wherever applicable and reasonable. The project has even contributed to the IMT2020 Evaluation Working Group in 3GPP, assessing that 3GPP Release 15 fulfils the ITU requirements for specific KPIs (connection density) with the global system simulator developed in WP2. This activity entails that the system simulator is compliant with the ITU framework (channel model, scenarios...).
As a result, the partners in ONE5G have significantly contributed to ongoing activities of 3GPP via the submission of Tdocs (for details see objective 7). Some of the technologies developed have been integrated into Release 15 (preemptive scheduling, RRC state) and other technologies are discussed in the framework of Release 16 Study Items and Work Items, or are postponed to subsequent releases (Carrier Aggregation, operation in unlicensed spectrum, NOMA, UE power consumption model, explicit CSI feedback schemes …)

Objective 3: To propose advanced link technologies and enhancements beyond Release 15 to enable multi-service operation and practical implementation of "5G advanced (pro)", with future-proof access schemes, advanced massive MIMO enablers and link management.

The first phase of 5G already defined several components of the link layer (such as numerology, coding scheme, waveforms, …). Thus, the contributions in WP4 of ONE5G are focusing on link level aspects not yet covered in Release 15, but which are crucial to meet the objectives of 5G. ONE5G has developed technical enablers for the concurrent operation of multiple services from distinct categories. Dedicated access solutions are therefore key to meet the requirements of latency and reliability for URLLC services (e.g. pre-emptive scheduling, enhanced retransmission schemes, grant-free access for avoiding scheduling delays), or to support the massive access of devices in the case of mMTC (e.g. NOMA, grant-free access for efficient resource sharing). Sophisticated massive access mechanisms also have been considered, with the proposition of the short packet structure to trade-off throughput, latency and reliability addressing the needs of mMTC services requiring a given level of reliability, though less severe as URLLC.

Another major area of the project is massive MIMO techniques. Our technical studies have focused on the design of flexible and low-complexity solutions for mMIMO, targeting practical implementations. These enablers are aiming at facilitating the implementation of mMIMO systems and include different methods to improve the CSI acquisition and feedback, reducing the pilot overhead. Solutions have also been proposed to reduce complexity and energy consumption with minimal impact on the performance, such as hybrid precoding instead of full digital precoding. WP4 has also developed solutions to facilitate the deployment of mMIMO systems, with recommendations on antenna array formats, highlighting the most appropriate array format depending on the user distribution (e.g. recommending wide arrays for urban environment with uniformly distributed users in the azimuth domain). The use of cylindrical arrays, with joint precoding over all antennas has been shown to provide coverage gains compared to sectorized planar arrays.

Coordinated transmissions for Centralized Radio Access Networks (CRAN) have also been studied, providing solutions to counteract the major challenges in CRAN, like CSI acquisition or interference management, such as for example enhanced physical layer procedures to minimize the feedback overhead for CSI acquisition in dense CRAN deployments, or resource allocation schemes, with scheduling algorithms clustering the users to achieve important cost and energy savings. Solutions have also been proposed to exploit CRAN deployment and benefit from the inherent multi-connectivity, such as cooperative techniques for cell-less communications or optimal functionality placement.

A high number of highly relevant outcomes and conclusions have been achieved within WP4 and are clustered in 11 technical areas. The techniques proposed have been evaluated through link and system simulations individually, and a subset has been integrated into the global system simulator developed in WP2, to be assessed in the whole system and combined with other techniques. Another subset of techniques has been implemented into the Proof-of-Concepts, showing the maturity of these solutions.

More specifics on the above listed advancements are following in the subsequent sections, within the public deliverables of the project and within the publications being produced by the partners.

Objective 4: To research and deliver highly generic performance optimization schemes for the 5G New Radio, in order to achieve successful deployment and operation, including optimizations for both the network operator and the E2E user-experienced performance.

A major ambition of the project is to improve the end-to-end user experience with the focus on RAN-related aspects. WP2 has defined Key Quality Indicators to formalize and measure the End-to End characteristics [D2.1]. WP3 has then developed and proposed RAN-based techniques optimizing E2E characteristics formalized via the Key Quality Indicator (KQIs), as introduced in deliverable [D2.1]. The project also leverages on context awareness to optimize performance and improve the E2E user-experience. Different directions are explored to achieve these optimizations.

In addressing this objective, ONE5G has first analysed the enhanced QoS architecture and protocol stack as adopted by 3GPP for the NR, as well as the UE power consumption model. Starting from the call-setup and control plane management perspective, ONE5G has developed recommendations for operating the improved three-state RRC machinery and DRX concept to efficiently leverage the trade-offs between user-plane performance and UE power consumption.

Secondly, numerous radio resource allocation enhancements have been developed that all help improving the end-user experienced performance. The enhancements proposed, aiming at optimizing the KQI on service integrity, include solutions for both distributed architectures, where scheduling is performed per cell, and centralized architectures, where scheduling is performed over multiple cells in C-RAN. As an example of technique in the distributed architecture case, we have provided recommendations on the use of pre-emptive scheduling or Multi-User MIMO null-space pre-emptive scheduling, depending on the number of antennas at the base stations, in order to improve the KQI service integrity for both eMBB and URLLC services.
Moreover, exploitation of state-of-the-art multi-connectivity solutions has been considered. Here we take advantage of the presence of multiple links to improve the system with respect to throughput for eMBB services (e.g. with data aggregation over multiple links), reliability (with data duplications over multiple links) and latency (exploiting the density of connections to prioritize low-latency users) for URLLC services... Multi-channel access solutions are also proposed, to enhance the operation of Dual / Multi–Connectivity and Carrier Aggregation.

Finally, the project has proposed solutions to optimize the E2E performance, leveraging on various means such as mobility or spectrum. Advanced traffic steering and load balancing schemes have been developed. Among others, it is proposed to migrate from traditional reactive schemes that aim for load equalization between cells, towards more promising context-aware proactive schemes that equalize the Quality of Experience (QoE) between the cells instead. Furthermore, schemes that rely on gathering information from social networks to predict where high traffic loads can be expected are developed, which is believed to be an important component for future network performance optimizations, i.e. to allow the network resources to follow the actual needs. The project also investigated solutions to optimize communications in a situation of mobility, for C-V2X applications or for high speed trains. Spectrum management has also been investigated, with solutions on dynamic spectrum aggregation and exploitation of both licensed and unlicensed (including both standalone and non-standalone cases) frequency bands to meet requirements from multiple services, mainly to boost the capacity and user data rates for eMBB services. Suitability of unlicensed frequency bands, used in standalone mode, has also been assessed for the different categories of services. Different network architectures are being investigated. In addition to traditional distributed deployments, enhancements for both CRAN and architectures with Multi-access Edge Computing (MEC) have been investigated, as well for D2D communications. Those include both solutions for eMBB capacity boosting and relay-based schemes for coverage enhancement and for reduced power consumption to better serve mMTC in challenging environments such as underserved scenarios.

The studies have reached promising results, validating the proposed solutions through system simulations in the context of the use cases and scenarios defined in WP2. The final report D3.2 summarizes the main outcomes of these studies and corresponding recommendations for future releases of 5G. This work has led to an important number of submissions in 3GPP. A subset of the technologies has been further assessed and combined within a system simulator in WP2, while other subsets of techniques have been implemented into Proof-of-Concepts (see under Objective 6 and WP5 accomplishments).

More specifics on the above listed advancements are following in the subsequent sections, within the public deliverables of the project and within the publications being produced by the project partners.

Objective 5: To identify the cost driving elements for the roll-out and operation and to propose adaptations to allow sustainable provision of wireless services in underserved areas under constrained circumstances.

Cost efficiency represents a main challenge especially in the “Underserved Areas” scenario, as currently less densely populated areas suffer from lack of mobile broadband connectivity due to the cost of deployment and operation of the network infrastructure. Population density in these areas is not high enough for an economically viable business case, and there is a risk that the advent of 5G could deteriorate further this situation, widening the gap between the dense urban areas, benefitting from the new services enabled by 5G and the rural areas lagging behind with basic connectivity.

The project has undertaken a techno-economic analysis, focusing on some of the use cases identified in the project. The partners selected a subset of the use cases defined within WP2, in order to cover different verticals (automotive, smart city, public safety), and to reach a good balance between the Megacities and Underserved Areas scenarios. The Underserved Area is the focus of one of the use cases, dedicated to long-range connectivity in remote areas, and considering both rural and extremely rural environments. The most appropriate deployment options have been considered for the following four use cases : automotive, smart city, long-rage connectivity, non-terrestrial networks for disaster and emergency communications. The cost-driving elements have then been identified, with an analysis of the main factors weighting the most on the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). In particular for this Underserved Areas scenario, the impact of different factors has been considered (such as height of the mast of number of sectors), to determine the most appropriate deployment configuration to extend the coverage, and the corresponding cost.

More generally, the project targets the development of solutions to account for the most critical specifics of the “Underserved Area” scenario, in particular coverage, power efficiency and cost. Resources can be constrained in “Underserved Areas”, with potentially limited power availability. Several technologies have been investigated, aiming at minimizing the energy consumption, such as optimized RRC state handling and Discontinuous Reception, or use of relaying mechanisms and D2D communications. Technologies aiming at increasing the range being considered are e.g. beamforming techniques (beamforming techniques for backhaul links, or signal shaping). A Proof-of-Concept has also been developed, focusing on key technologies developed for this scenario.

Objective 6: To validate the developed extensions and modifications through different approaches: analytically, by means of extensive simulations and with the help of proof-of-concepts for selected aspects.

We have applied various means to assess the relevance and the capabilities of the different technologies ONE5G has proposed and investigated. When in early stage, i.e. while having still a rather wide set of options and paths to follow for a specific technology component, we have applied analytical means and rather specific and narrow simulation activities to further develop the idea towards being more concrete and to get an idea about the improvements to expect. As a next step, i.e. when having nailed down the specifics of the proposed technology in more detail, while still having a set of degrees of freedom (e.g. w.r.t to parametrization), extensive simulations (both on system and on link level) on a per partner level have been conducted to get a clear view on those parametrizations and to assess the performance gains in a more concrete setting. Ultimately, a selected set of mature technologies have been transferred to the project wide system simulation tool being provided by WINGS.

This project wide system simulation tool has been developed gradually, integrating 6 innovations from different partners, in collaboration with the owners of these innovations. These bi-lateral collaborations between WINGS and the technologies owners guarantees compliance with the original ideas and validation of the results. Some of the techniques have then been combined for further assessment. The project also participated to the 5G-PPP IMT-2020 Evaluation Working Group through this simulator, simulating the 3GPP proposal submitted to ITU and assessing the performance of this proposal on specific KPIs.
As a last step, another subset of technologies has been integrated into the five Proof-of-Concepts developed within the project. A total of 23 technical components have been integrated into the various testbeds, allowing measuring the gains in a real but simplified environment, accounting for hardware imperfections and impairments. These PoCs have been exhibited at various events: MWC 2018, EUCNC 2018, MWC 2019 and EUCNC 2019. The project even won the “best booth award” in EUCNC 2018.

Objective 7: To produce a high number of valuable contributions to relevant conferences and the printing media (>50), a reasonable amount of IPR (>10) and partner specific standardization contributions.

During the period being reported in this document the partners have produced up to now 141 publications (partly still in submitted status) for various conferences and magazines/journals, 7 invention filings and so far 52 partner specific standardization contributions..

3 Overview on scientific results and recommendations

3.1 System Requirements, Integration, and Evaluation

The work package objectives are as follows:

- To define in detail the scenarios, use cases, the set of relevant services and associated KPIs (including potentially new KPIs for E2E optimization) to be adopted for the development and evaluation of the proposed solutions in the project. Ensure the requirements of the services and the associated verticals are adequately addressed in the project.
- To assess the means required to integrate the technical solutions and performance optimization schemes developed in WP3 and WP4 into subsequent 3GPP releases of 5G systems in terms of e.g. specification impact and phasing.
- To validate the most promising extensions and modifications developed in WP3 and WP4 through system-level simulations and evaluate the gains over the 5G system as defined during the lifetime of the project at that time.
- To perform techno-economic analysis with emphasis on 5G vertical applications.

WP2 deals with defining the baseline to be used by the project partners, e.g. the detailed system characteristics and requirements in the form of scenarios and use cases with clear KPIs. A second work stream is the evaluation on system level of selected technical solutions developed by WP3 and WP4 in a holistic manner. In addition, WP2 provides some in-depth techno-economic analysis on selected use cases, which highlights the opportunities and challenges in implementing some of these use cases. The progress made on the key objectives of WP2 over the project's lifetime is detailed in the sections below. This description is provided per task, where the first objective (bullet points above) is covered in Task 2.1 and the last three objectives are covered in Task 2.2 sections.

3.1.1 Scenarios, KPIs and requirements

The scenarios, KPIs and requirements development work was completed in year 1 and reported in [D1.1]. However, in year 2, WP2 accumulated the work carried out in WP3 on KQI definition and assessment and presented a summary of this work at the 5GPPP KPI working group (WG) workshop in Kista, Sweden in November 2018.

In terms of KPI evaluations in the project and handling of extreme thresholds, for all the main KPIs the deliverable [D2.1] of WP2 defines some challenging values to be attained by the technical work of WP3 and WP4. Some of the technical components developed in these WPs have been analysed through system level simulations and the extreme KPI attainment has been verified. One clear example is the K-repetitive HARQ TeC from WP4 showing the achievement of 1 ms latency levels as an extreme KPI in the system level simulations (reported in [D2.3] and also discussed below).

3.1.2 System Evaluation and Integration

This task contained both the System level simulations and integration work plus the techno economic studies on the selected use cases. The final results and key recommendations from both these work items will be highlighted below.

The system level evaluation of selected Technical Components (TeCs)

The system level implementation and evaluation were done on a set of technologies and optimization techniques that have been proposed in WP4 and WP3 respectively. The implementation was realized on a 5G system level simulation tool which was extended for including the proposed ONE5G TeC features. Specifically, the simulator was extended to support the main enabling technologies targeted by the project including the centralized multi-cell scheduling, component carrier management, context-aware proactive QoE traffic steering, massive MIMO, enhanced HARQ and optimized functionality placement and resource allocation in CRAN/DRAN. The simulations were specially designed to feature 5G-NR features, so the performance of these TeCs can be ascertained in a 5G context. In addition, a set of environmental models was implemented in order to capture the different characteristics of the defined cases of the project. In detail, we implemented realistic user/device spatial-temporal distribution models, mobility models, service/traffic models and node distribution models taking into consideration the characteristics of the targeted cases to be evaluated.

The main results from the simulations of each of the six TeCs and also the analysis of a combined TeC implementation are discussed below.

Centralized multi-cell scheduler

This TeC concept is based on a centralized scheduler, which looks at the CQI reported from the UEs from each of the base stations the UE can measure. The scheduler allocates the UEs to the most suitable base station. A serving Macro cell and a layer of small cells are considered in the analysis. The scheduling is based on proportional fair algorithms, so the UEs with even lower MCS reporting will get an opportunity for transmissions. The initial results of the integration of this TeC were reported in [D2.2] and [D1.1]. In the later stages of the work, 5G features of NOMA and CoMP were incorporated into the simulations. Different active user numbers were considered in the simulations, and throughput improvements ranging from 15% to 40% were recorded for different combinations of the NOMA and CoMP levels. An interesting finding with the

NOMA inclusion was that the lower MCS users would get more of a resource allocation percentage, with higher NOMA factors, increasing the fairness of the overall system.

Component carrier manager:

The second technical component evaluated is a component carrier (CC) manager, where the current practice is to assign resources from two carriers (dual connectivity) to a UE, considering its radio conditions. The aim of this work is to dynamically assign Component Carriers from multiple (more than two) nodes (extending dual connectivity) according to the network state (e.g., network load or coverage hole), as well as the service category and context information [D3.2]. In this study, only eMBB is initially considered and it is shown that as the number of component carriers increases, the throughput increases proportionally and the delay decreases. This is a form of resource aggregation to increase the throughput. This CC manger can also be configured, for example, to optimize URLLC traffic, where resource duplication can be utilized to enhance reliability.
The reported simulation results in [D2.3] looked at different bandwidth component carriers and compared the performance with RSRP based CC selection against a proposed RSRQ and load based CC selection. The latter proposed scheme outperformed the former RSRP based scheme in all the cases, while achieving on average an increase of 10% in the average downlink throughput. The simulations with up to 4 CCs each with 100 MHz bandwidth should be particularly noted, as this demonstrated a typical 5G scenario with wider bandwidths.

Context aware QoE traffic steering

This technical component aims to develop a set of tools to improve mobility management in 5G NR, in order to optimize the quality of experience (QoE) perceived by an end user. To that end, and in order to have a closer view to that of the end user, first, radio access network performance indicators are left aside in favor of metrics related to the QoE associated to a certain service. These will be used as the input for mobility management use cases, like load balancing, leading to a QoE balancing. The main objective of this TeC, as implemented in the simulator, is to achieve a QoE balancing by adjusting handover margins.

The simulations targeted QoE optimization for the services provided under eMBB in 5G by defining and evaluating a figure of merit. The simulations considered a large number (1000 to 3000) of FTP and Web users and the average QoE was evaluated. The results indicate that for the successive iterations of the algorithm, the QoE converges to a stable value and this stability is achieved only after 2-3 iterations. As a further extension of the study, a Figure of Merit (FoM) has been defined for the QoE imbalance between users and the simulations tested how this FoM would stabilize through iterations. Further results indicate the FoM convergence stability for both FTP and Web traffic users.

Massive MIMO

The Massive MIMO TeC was the first TeC integrated into the system level simulator from the PHY layer oriented WP4. This TeC was particularly challenging to implement, as effective PHY abstraction methods need to be developed to analyze Massive MIMO performance in the system perspective. System level evaluation of massive MIMO in cellular systems is computationally and storage wise very demanding due to the large antenna dimension and many devices required utilizing spatial multiplexing gains. Considering also realistic traffic models, simulations have to cover a time range in the order of hundreds of milliseconds, so an additional abstraction model besides the SINR-to–rate mapping is required.

Overcoming these challenges, the SLS platform was developed for the TeC, where the simulations compared the performance of a uniform planar array (UPA) and a uniform circular array (UCA). The spectral efficiency curves for the geometry (uncoded) SINR was used as the abstraction method. The interference component in the SINR comes from the consideration of multiple cells in the simulations. The results were derived for various eMBB scenarios, where the data rate and the number of users per cell are primarily varied. The obtained results indicate that the UPA outperforms UCA when the number of active users in the system is lower and reverse happens when the number of users is higher. The UCA is able to provide uniform coverage across the 360º azimuth angles and this becomes beneficial with higher number of users, as then, the UCA is able to effectively beamform to each user.

Enhanced HARQ

The enhanced HARQ TeC was developed to reduce the latencies in the HARQ process, to make it suitable for the low latency traffic. In the K-Rep variant studied here, the UE is configured to autonomously transmit the same packet K times before waiting for feedback from the BS. Each repetition can be identical or be different redundancy versions of the encoded data. This method can reduce the delay in the HARQ process, with a potential waste of resources if the number of repetitions is overestimated.
The simulations considered a traffic mix of URLLC and eMBB services, where the proposed K-rep HARQ scheme was applied only to the URLLC traffic. The results indicate that for 4 repetitions, the URLLC traffic can achieve the below-1ms latency, which it the current threshold for this type of 5G traffic.

Optimised functionality placement and resource allocation in CRAN/DRAN

In this TeC, a network architecture that contains a Central Unit (CU) and several Distributed Units (DUs), integrating the DU and remote radio head (RRH) in the same node is considered. A CU (e.g. BBU) is a node that includes the gNB functions, except those functions allocated exclusively to the DU. It controls the operation of DUs over front-haul interface. A DU (also referred to as RRH) is a node that includes a subset of the gNB functions, depending on the functional split option. Its operation is controlled by the CU.
Based on the functional split options proposed in [5GPPP-ARCH] and also discussed in Sec. 2 of [D3.1], the functions of the LTE protocol stack are studied, which can be partitioned in distinct elements and assigned to different network units. The objective was to assign these functional elements to network units finding the minimum cost allocation that satisfies a set of capacity and performance constraints, as well as the distribution of network traffic to each DU. The factors contributing to cost are mainly energy consumption and latency, for computation as well as data transfer among the functional components. The applied constraints address capacity and QoS requirements.

The simulations look at the distribution of traffic to the distributed units for two different use cases with their respective QoS requirements is depicted. In one case, the QoS requirements are not as strict, so only 3 of the available DUs are activated, leading to reduced operational costs. However, the second case, QoS requirements are higher (resulting from a higher ratio of URLLC use cases). Therefore, more DUs are required in order to handle the traffic. These were proof of concept results, showing that the solution adapts to varying conditions and decisions intuitively show some improvement. The objective function and parameters used were also described in [D4.2]. Additionally, the reduction of the cost function for different mixtures of traffic types (eMBB, URLLC and mMTC) was demonstrated.

Combined TeCs of Component Carrier Manager and Massive MIMO

Through this combination, it was possible to show potential synergies between different technical components. The PHY layer adaptation of massive MIMO can easily complement with the higher layer component carrier management, in a practical sense.
In the simulations, the component carrier (CC) manager TeC is considered as a baseline and the massive MIMO TeC is added onto this. The results indicate that the throughput with the usage of MIMO tends to be around 20-30% higher compared to the baseline.

3.1.3 Techno-economic studies on the selected use cases

The selected use cases for techno economic studies consisted of a mixture of different vertical areas and a good balance in addressing challenges in both the Megacity and Underserved area scenarios. In year 2 of ONE5G, we focussed on developing the quantitative assessments, mainly looking the TCO (Total Cost of Ownership) variations for different deployment options in these use cases. The requirements from the use cases and consequently the network features are inherently different. Yet we have endeavoured to align these analyses as much as possible, utilizing common approaches like the same 3GPP centralization options 2 and 7 [TR38.801]. The CRAN split option 2 is at the higher PDCP layer, while the split option 7 is at the lower PHY layer. These comparisons are noted below, after detailing the results and recommendations from each of the use case studies.

Provision of cellular V2X for the Automotive vertical

The TE study focuses on deploying a Greenfield network both in Mega-city and Rural areas specifically to serve the V2X applications. The networks will include a MEC (Multi-access Edge Computing) node nearer to the RAN to reduce the latencies. In the centralized options the MEC node will be co-located with the CU (Centralized Unit) and in the Distributed RAN (DRAN) option the MEC node will be co-located with the Backhaul network aggregation point.

Comparing the results from rural scenarios and megacities it can be observed that the TCO for rural scenario is higher than for megacities. The OPEX cost is lower for rural scenarios, since these scenarios do not need a high capacity at the fronthaul and backhaul networks. However, the number of sectors aggregated per CU is lower for these rural scenarios, therefore, the capital investment needed is significantly higher and thus, the total cost per sector is higher for rural scenarios. The number of V2X users in the rural areas is likely to be lower as well, so the total cost per user will also be higher for the rural deployments.

The CAPEX directly depends on the number of sectors that are aggregated by one MEC in a central office. CRAN split 7 deployment presents the lowest CAPEX as it mainly relies on the use of general-purpose hardware at the central office instead of using dedicated hardware. However, CAPEX derived from CRAN split option 2 configuration is slightly higher than DRAN traditional deployments because, despite these CRAN deployments benefits of centralization and the use of general-purpose hardware, they have to deploy an extra unit, the CU, hence, increasing the CAPEX.

A CRAN low-layer split deployment presents higher OPEX than a high-layer split deployment, due to the required extra capacity at the fronthaul network that is required in split option 7. Nonetheless, the most cost-effective topology is CRAN split 7 due to the notable CAPEX reduction.

Provision of IoT services for the Smart city vertical

The main consideration in this TE study is to identify the additional in-band radio resources needed for NB-IoT and LTE-M services, when the IoT deployment moves from 5G Rel.15 to Rel.16. The additional demand for the IoT services is estimated by assessing the demand in Paris in 2020 for a number of IoT services [D2.3] and then extrapolating this demand to 2030, to fit in with a release 16 deployment. The technical specifications for the IoT network are derived from a 3GPP study paper. The software upgrade costs from Rel.15 to Rel.16 IoT solutions are considered to be minimum and the sensor device costs are not considered in this study.

Considering the numbers for Paris 2020 as a basis for Rel. 15 and those for Paris 2030 as a basis for Rel. 16 the analysis has shown that, depending on the deployment settings and the traffic model, up to 6 additional PRBs (one additional narrowband respectively) would be necessary for NB-IoT (LTE-M respectively) between Rel. 15 and Rel. 16 to satisfy the number of devices envisioned for Smart cities applications.

In terms of bandwidth our study has shown that up to additional 1.08 MHz in the 700 MHz frequency band would be necessary between Rel. 15 and Rel. 16 to satisfy the number of devices envisioned for Smart cities applications. This represents around 5 % of the maximal 20 MHz bandwidth that should be assigned for each 5G network at this frequency band. In fact, 5G mMTC services should be deployed in low frequency bands but also in medium frequency bands (between 2 GHz and 6 GHz) for which the recommendations are to assign at least 100 MHz contiguous bandwidth. Considering that the resource allocation for both NB-IoT and LTE-M is very dynamic and a 5G small cell underlay will cater for most of the eMBB traffic, the spectrum cost of smart cities applications over eMBB and URLLC applications should not be too high.

Provision of long-range connectivity for rural and far remote areas

This use case is exclusively focussing on the underserved area scenario of the project and a number of deployment options for extending the coverage have been studied, with target ranges for rural set at 50 km and for far remote set at 100 km. The peak data rates targeted are 50 Mbps (downlink)/ 25 Mbps (uplink) for rural and 2 Mbps (downlink)/ 0.256 Mbps (uplink) for far remote areas. The options include increasing the antenna height, adding vertical diversity with multiple antenna floors, increasing the number of antennas in MIMO and massive MIMO options and increasing sectorisation. Some key findings from these studies, conducted on a 5G simulator, are noted below.

Increasing the antenna heights in rural areas have a positive impact in reducing the TCO per km^2 area. However, this does not have an impact in the far remote areas. The main reason is that the microwave links needed for backhaul need to have repeaters over long distances and this offsets any savings increasing the access coverage in far remote areas.

Increasing the antenna numbers increases beamforming gain both in the downlink (transmission) and uplink (reception) and thus help to increase the coverage and also reduce the TCO per km^2. For the rural coverage, massive MIMO options are also considered at 3.5GHz with 64 transmit antennas and this draws the deployments nearer to capacity targets although the coverage targets are not met. Similarly increasing the number of antenna floors adds vertical diversity and provides increased coverage and reduced TCO per km^2. Increased sectorisation improves the coverage and also the overall capacity and reduces TCO per km^2. All these options incur a power penalty at the transmitter, as to maintain the same total power, the power per each component studied needs to be reduced. The key observations from the simulations are as follows:

- When dividing by two (from 80W to 40W) the transmitted power per sector in the case of 6 sectors, there is no impact on the coverage.
- When dividing by two (from 80W to 40W) the transmitted power per sector in the case of 4 floors, there is no impact on the coverage.
- When dividing by two (from 80W to 40W) the transmitted power per sector in the case of MIMO4x2 DL, there is no impact on the coverage.

The backhaul/fronthaul options were also considered, with the 3GPP CRAN splits implemented in the simulations. A number of options including satellite, fibre and microwave were studied. The satellite options return very high TCO and a 50%/50% combination of fibre and Microwave links provide the best option in terms of lower TCO. The costs are dominated by the CAPEX component and many of these are common to both CRAN split 2 and 7 options. Hence there is no notable difference in TCO for these split options.

In terms of cost driving elements in this use case, these are predominantly CAPEX components, required to provide the extended coverage. These can be in the form of additional infra-structure (antenna masts), relay stations, power amplifiers or more complex antenna arrays. These are upfront investments for an operator and have traditionally deterred these kinds of deployments as the anticipated revenue streams do not match up to the huge upfront expenditure.

Provision of 5G eMBB through drones for the disaster and emergency vertical

This study looked at providing 5G eMBB services to emergency services throughout their service area on an ‘on demand’ basis. The ‘last mile’ of wireless connectivity will be provided by a number of rapidly deployable drones and an existing network of 4G and 5G small cells will be utilized for relaying the fronthaul back to the BBU. Three main cost components were identified in the study: the unit cost of drones and drone RRH, the small cell upgrade costs and the costs of increasing the fronthaul and backhaul capacities of the existing centralized ground cell network. A number of studies on cost sensitivity were also conducted and the study was concluded with analyzing the opportunity cost impact of allocating 25% of the commercial 5G spectrum for this ‘on-demand’ service.

The key results on the TCO estimates point to a lower cost for using the CRAN split 2. In the TCO breakdown, the CAPEX and OPEX have roughly equal weight, as the proposed network utilizes existing small cells, fronthaul links and BBU for ground connectivity and the higher fronthaul capacities incur higher OPEX. The cost benefits of using CRAN split 2 is more pronounced in the 5-year TCO indicating the higher OPEX savings on the fronthaul provided by this option.

The cost sensitivity studies indicate sweet-spots for operation in terms of the number of drones used for the wireless part of the link, when the drone RRH unit cost and the capacity of the link are considered. These studies indicate significant variations of the TCO in terms of the above factors and would enable such networks to be planned with either cost or performance optimizations.

The related spectrum study looked at the spatio-temporal correlation probabilities of nascent 5G small cell traffic and the emergency events. The 5G network was assumed to start with a single commercial area deployment in year 1 and then one additional residential deployment in each of the next 4 years. The emergency events correlated temporally with the traffic peaks of the residential areas. Hence in year 1, there is minuscule impact on re-allocating the 25% of commercial spectrum. Although the individual impact on each of the residential cells in the next 4 years is higher, the overall impact on the system capacity is negligible.

Results comparison and recommendations

The main comparison of the results come from the CRAN split options. The lowest TCO in terms of the CRAN split 2 or 7 depends highly on the network features. For the automotive use case, the Greenfield network incurs high CAPEX and the OPEX are low due to the low/medium data rates of the mainly URLLC traffic. This contrasts highly with the drone based 5G services use case, where the OPEX are very much comparable with CAPEX, due to the high fronthaul capacities of the eMBB services and lower CAPEX by re-using the existing ground network. The long-range connectivity use case also show very high CAPEX compared to OPEX, but most of these CAPEX is applicable to both CRAN split options as means of extending the wireless coverage. All these studies indicate that the choice of CRAN options is very much use case dependant. Our main recommendation from the TE studies would be that the cost components and hence the best CRAN options would vary significantly on the nature of the use case and any pre-determinations should not be done. Careful analyses are always needed on the network features that can meet the unique KPI combinations and this will lead to a more sensible option selection.

The spectrum analysis in the drone based use case revealed that even a 25% of the spectrum can be re-allocated without much impact to the emergency services, due to the nascent nature of the 5G network and probabilistic behaviour of emergency events. Similar observations/conclusions were drawn for the Smart city IoT network use case, where 2%-10% of the spectrum will be utilized for the IoT services. These studies indicate some examples of licensed shared access of spectrum between different verticals, possibly implemented as end-to end network slices. The apparent possibility for co-existence is a good indicator for future deployments, which will see the high demand for spectrum will make exclusive use practically impossible. These examples shared spectrum usage will be presented to the 5GPPP spectrum WG, to widen the dissemination of these study results.

3.2 E2E multi-service performance optimization

The overall work package objectives are as follows:

- Orchestration of an advanced multi-service 5G system to achieve optimized E2E performance, utilizing context awareness information when appropriate.
- Performance optimization of the radio access network (RAN) part is in focus, but also interaction with higher layers such transport protocols and applications are within the scope.
- Go beyond the traditional multi-service definitions of eMBB, mMTC, and URLLC, and study novel performance optimization techniques also for specific services within those broader categories, addressing E2E performance metrics as will be defined within work package 2.

WP3 have presented final recommendations regarding the technologies and innovations with the aim of optimizing the E2E performance of the 3GPP 5G NR (see details in ONE5G [D3.2]). The developed enhancements are largely generic in the sense that they are applicable to both the considered Megacity and Underserved scenarios. It is noted that the E2E performance benefits of each innovation are defined based on the KQI framework that allows to highlight the E2E aspects. The proposed solutions were validated by a mixture of semi-analytical and heuristic methods, including examples of proof of optimality for selected cases, wherever the derivation of such proofs was feasible. Tools from classical optimization theory and machine learning discipline have also been widely utilized. Throughout the project duration, the NR system design principles and performance assessment assumptions have been adopted to closely follow the 3GPP guidelines. In Chapter 5 of [D3.2], we furthermore presented a summary of how a selected set of the developed E2E performance features are linked to 3GPP standardization of NR. From this it is visible that ONE5G have had some early links to 3GPP NR Rel-15 (a.k.a. the first 5G standards release) and has conducted research resulting in impact for the ongoing NR Rel-16 standardization process, as well as has developed a promising set of forward-looking features that may be considered for future NR Rel-17 and Rel-18 standardization activities. In the following sub-sections, we present further summary of the WP3 key achievements, including related recommendations and main E2E performance benefits.

3.2.1 Optimized RRC and DRX state handling, incl. UE power management

5G NR has introduced several improvements that can help to reduce the power consumption of UEs. To study the optimal configuration of e.g. DRX parameters and use of RRC modes, a 5G NR power model has been proposed. The model accounts for the consumption in relation to the type of transmission or reception, the transmit power, the number of active transceivers, and the used bandwidth. This is achieved by introducing new dedicated UE power states and power scaling. It is noted that this model has been accepted by the industry as part of the 3GPP Release-16 study on UE power savings in NR [3GPPTR-38840]. The model is employed to study the best use of the newly introduced RRC_inactive mode with DRX for different UE profiles in terms of traffic intensity, mobility profile and latency requirements. Distinct policies that deliver significant improvements in power consumption and control plane and data plane latency are identified for the different use case.

Based on extensive system-level performance analysis, it is apparent that optimizing the RRC state handling exploiting the RRC_Inactive state is rather beneficial. Numerically, RRC_Inactive can lead to reduced latency for network/service access, achieving up to 89% shorter control-plane latency at RRC state transition to RRC_Connected, as compared to RRC_Idle, i.e. 8ms vs 76ms. Further, RRC_Inactive can lead to higher service retainability, achieving ~70% longer battery life compared to RRC_Connected in no data scenarios, and ~40% extended battery life for infrequent packet arrival. In addition, it can achieve good service integrity, with an overall low latency, where the latency increase compared to RRC_Connected can be limited to ~10% for infrequent traffic. We therefore recommend optimizing the RRC state handling as follows: First, the RRC state handling should be optimized as a function of the service/traffic requirements (e.g. packet inter-arrival rate at a UE and QoS requirements), by setting properly the RRC connection suspend timers. Longer timer settings (hundreds of millisecond or seconds) can be used when more frequent traffic is generated. Vice-versa, shorter timer settings (down to few tens of millisecond) can be used for infrequent traffic, allowing to timely move a UE to RRC_Inactive benefiting from its power saving properties. Furthermore, the optimization of the RRC state handling should consider the mobility profile of a UE as well, attempting to limit the mobility related signalling to the RAN / CN which may be required for UEs in RRC_Connected. Specifically, RRC_Connected with long DRX can be used for (semi-)stationary UEs having medium/high traffic frequency. Limited mobility related signalling and UE power savings are achieved thanks to DRX and because of the UE stationarity state.

Power consumption is also impacted by the use of bandwidth parts (BWP), which allows to support simultaneous operation of UEs with small and large bandwidths in the same carrier. For traffic with variable load, timely adaptation of the used bandwidth can lead to reduced UE power consumption. Different policies for setting the BWP inactivity timer have been considered, and it is concluded that timer should be set based on the link quality of individual UEs, as HARQ activity can trigger BWP switching signaling.

The following Table summarizes the key recommendations related to UE power consumption optimizations, as well as their benefits in terms of improved E2E / KQI. For further details, see ONE5G [D3.2].

Table 3-1 - Summary of key recommendations and benefits in terms of UE power consumption

Feature	Recommendation	E2E / KQI benefits
Service dependent RRC state handling	RRC state handling to be optimized for latency, UE power and network signalling based on service/traffic requirements as well as mobility profile of a UE. Key recommendations: RRC_Connected with long DRX to be used at medium/high traffic for semi-stationary UEs. RRC_Inactive with longer DRX to be used for infrequent traffic and low/medium mobility profile. RRC_Idle mode usage to be limited only at high mobility.	It achieves reduced network/service accessibility (i.e. shorter control-plane, CP, latency), service retainability (i.e. longer battery life), and better service integrity (overall lower user-plane latency): Up to 89% shorter CP latency at transition from RRC_Inactive to Connected (compared to Idle). ~70% / ~40% longer battery life of RRC_Inactive compared to Connected in no data scenarios & infrequent traffic, respectively. Only ~10% latency increase of RRC_Inactive compared to Connected for infrequent traffic.
Efficient BWP inactivity timer configuration	BWP inactivity timer shall be configured according to the UE link quality, e.g., in terms of the retransmission probability so that the overall UE power consumption can be optimized.	Improved UE power efficiency. Specifically, when UE's operation bandwidth can timely follow the actual traffic needs so as to minimize the unnecessary large bandwidth usage, the power consumption can be significantly reduced, (e.g., BW reduction from 60 MHz to 20 MHz can decrease ~ 40% power consumption).

3.2.2 Multi-service and context aware radio resource management optimization

The 5G NR comes with an enhanced QoS architecture and RAN protocol stack. In achieving context awareness, the new SDAP (service data adaptation protocol), in charge of mapping the E2E PDU sessions to QoS flows to DRBs, is of importance. This mapping is based on 5G QoS class indices (5QI), and opens opportunities for applying SDAP scheduling policies, sometimes referred to as higher-layer application-aware scheduling, or advanced QoE management. Given this starting point, the MAC scheduler will act on QoS metrics of the DRBs. The suite of new options for enhanced multi-service scheduling and context aware options where originally reviewed in ONE5G D3.1, given the 3GPP NR Rel-15 RAN protocol stack design. A set of complementary techniques enhancing the multi-service aware radio resource allocation methods has been finalized and documented in ONE5G [D3.2]. A challenging service is URLLC, where delay optimal user and channel scheduling policies has been derived. Including also solutions for dynamic resource allocation for URLLC services in the absence of CSI at the transmitter side. For efficient scheduling of URLLC type of traffic, specific low complexity solutions taking latency constraints, possible payload segmentation, HARQ effects, radio channel conditions, and control channel overhead from scheduling grants, have been developed. Moreover, solutions for periodic URLLC traffic, subject to clock-drifting, have been developed for cases where configured grants are applied. Here the proposed scheme continuously adjust gNB estimates of traffic periodicity and time of arrival of the next packet, resulting in reduction of overhead that allows supporting a higher number of URLLC uplink users.

For cases with a mixture of eMBB and URLLC service categories, the problem of scheduling UEs with different numerologies in terms of TTI sizes is addressed. An enhanced pre-emptive scheduling framework is found to be promising, where the base components have been adopted in the 3GPP NR Rel-15 specifications (see e.g. the 3GPP Stage-2 specifications in [TS 38.300]). The performance of those techniques has been evaluated by means of advanced system-level simulations. In order to get an E2E performance perspective, eMBB file down load over TCP has been studied. It is basically found that the impact on KQI for file transfer (i.e. the service integrity category) results in only moderate longer eMBB file download times as result of being pre-empted, while still fulling the URLLC requirements (and its KQI service integrity counter). For deployments with eight or more gNB antennas per cell, a novel MU-MIMO null-space preemptive scheduling solution has been developed.

For more advanced C-RAN architectures, it is possible to further optimize the performance by means of centralized multi-cell resource allocation methods. The optimum multi-cell resource allocation solution is, however, very complex, and therefore difficult to realize in practical implementations. ONE5G has therefore developed low complexity solutions. This includes a low complexity fast dynamic multi-cell scheduling of URLLC users (from one cell per TTI). Based on UEs reporting at most CSI measurements from the strongest 2-3 cells within a received power window of 6dB are being taken into account. Segmentation of URLLC is beneficial if limited to at most one UE per cell per TTI. Simpler DPS URLLC multi-user resource allocation is found to also be attractive. Also, attractive throughput oriented centralized multi-cell scheduler methods for handling eMBB traffic in dense scenarios with very large number of users connected have been developed and proven to result in attractive benefits. In this context, it is worth noticing that the uplink eMBB capacity benefits are much larger in the uplink and as compared to the downlink for the evaluated dense megacity scenarios based on Manhattan and Canonical simulation scenario models (see Table below). Common for those centralized multi-cell scheduling methods is that they explore multi-cell radio channel diversity and fast multi-cell load balancing to enhance the performance. Thereby also reducing the probability of users experiencing queuing delays (as is particularly critical for URLLC use cases).

The following Table summarize the key recommendations related to multi-service and context aware radio resource management optimizations, as well as their benefits in terms of improved E2E / KQI. For further details, see ONE5G [D3.2].

Table 3-2 - Summary of key recommendations and benefits for multi-service and context aware radio resource management optimization.

Feature	Recommendation	E2E / KQI benefits
Delay optimal user and channel scheduling	Myopic scheduling policies (e.g. max weight which is throughput optimal, etc.) are suboptimal if the KPI/KQI is the average delay.	30% improvement of average packet delay (service integrity) for eMBB users. Asymptotic optimality (in terms of average achieved delay) can be reached for some scenarios.
Dynamic resource allocation for URLLC services	For the cases where the CSI is not available at the transmitter, dynamic RB allocation for URLLC services can provide substantial gain as compared to static policies (i.e. that always allocate a fixed number of RBs to increase robustness).	50% improvement of service reliability and delay for URLLC services (if CSI is not available), higher supported throughput
Spatial and temporal availability of URLLC services	Jointly consider space & time in resource allocation for availability/ reliability improvement.	Improved service availability/ reliability considering a URLLC service area (e.g., a factory floor).
Downlink multiplexing of eMBB and URLLC service	Use preemptive scheduling for cases with moderate number of	Improved KQI service integrity for both the URLLC and eMBB

classes	gNB antennas (supported in NR Rel-15). For deployments with eight or more gNB antennas per cell, use the developed MU-MIMO null-space preemptive scheduling solution.	users, higher supported offered load per cell, so clear E2E performance benefits. The MU-MIMO null-space preemptive scheduling solution offers 60% capacity improvement.
C-RAN multi-cell scheduling of URLLC traffic	Take advantage of low complexity fast dynamic multi-cell scheduling of URLLC users (from one cell per TTI). Based on UEs reporting at most CSI measurements from the strongest 2-3 cells within a received power window of 6 dB. Segmentation of URLLC is beneficial if limited to at most one UE per cell per TTI. Simpler DPS URLLC multi-user resource allocation is found to also be attractive.	Significant reduction (factor of two) of the experienced latency at low outage levels. Higher offered (30%-60%) aggregated URLLC traffic can be tolerated without violating the latency and reliability requirements. Improved KQI service integrity. The simpler form of centralized DPS URLLC scheduling offers up to approx. 30% latency reduction.
C-RAN multi-cell scheduling of eMBB traffic.	Centralized multi-cell scheduler for handling eMBB traffic is more suitable for high dense scenarios with very large number of users connected.	Improved average throughput per cell around 150% DL and 260% UL in a Manhattan scenario; and around 77% DL and 260% UL in canonical scenario. Ensuring all users obtain resources.
Configured grants for periodic non-synchronous uplink URLLC traffic	Use proposed scheme to continually adjust BS' estimate of traffic periodicity and time of arrival of next packet.	The possible reduction of overhead allows to support a higher number of URLLC uplink users. For 1ms latency requirement, 3 or 30 times more UEs using 10ms or 100ms cycle time can be supported, respectively. In other words, the availability KQI is significantly improved.

3.2.3 Signalling and control plane optimizations, including virtualization and robustness against failures

A central component of 5G is C-RAN, where some BS processing functionality is centralized in the network to enable advanced scheduling and cooperation schemes. While these advanced scheduling and cooperation schemes can offer significant performance gains, they pose strict requirements to fronthaul performance. The degree of use of C-RAN (i.e., at which protocol layer should functionality be centralized) in different scenarios should therefore be carefully considered in terms of the relevant trade-offs. The two main options considered are the low-layer split (LLS) in [5GPPP-ARCH] also called split option 7 in [TR38.801] and the higher layer split (HLS)/ split option 2 , the terms are used interchangeably. While LLS is performance-optimal whenever it can be supported by the operator's infrastructure, it is also a costlier option, since the fronthaul requirements in terms of capacity and latency are much stricter than a HLS. The two split options have been analyzed for the ONE5G Megacities and Underserved Areas scenarios, where LLS was preferred for the former scenario and HLS for the latter.

Enabled by the C-RAN network architecture, network-based device virtualization has been considered as a method for offloading computational and storage demanding tasks to a network-based device virtualization server, thereby giving the user the impression of a much more capable device. Network-based device virtualization brings great benefits for users as it allows them to have unlimited access to different services without the need to change their physical devices due to OS (Operating System) incompatibilities, lack of capabilities, etc. Additionally, it gives the possibility of managing all the connections within an area in a centralized way, which are of great interest in closed-spaces such as mega factories. Figure 3-1 below illustrates some of the network functionalities that are moved to DVS so as to allow the users to have simpler devices with the same or even higher functionalities.

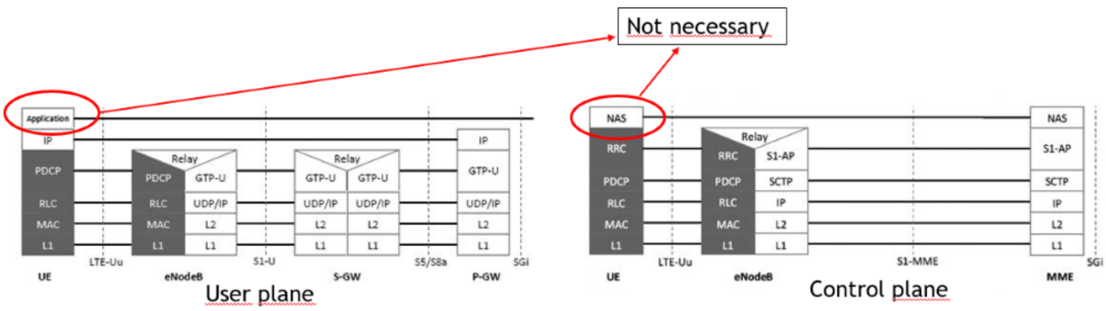

Figure 3-1: DVS impact on user and control plane protocol stack.

A prerequisite for this approach is that the central unit (CU) has full knowledge of e.g. channel conditions of all cross-links. As this is hardly feasible to obtain in complex scenarios, a compressive sensing method is investigated as a solution to estimate the required link conditions. Simulations have shown promising results for this approach as it is found that the signaling overhead for a downlink training sequence in a dense C-RAN deployment can be decreased by around 87%, meaning that a C-RAN with up to approximately 500 RRHs can be supported by a single CU.

The following Table summarizes the key recommendations related to control signaling optimizations, as well as their benefits in terms of improved E2E / KQI. For further details, see [D3.2].

Table 3-3 - Summary of key recommendations and benefits for control signaling

Feature	Recommendation	E2E / KQI benefits
Device Virtualization	DVS introduction allows to host some of device functionalities (less protocols in SW stack) and abstract users from CN interaction. To support DVS introduction in a CRAN deployment a maximum number of RRHs = 500 is recommended, as well as, a CS approach for CSI estimation under pathloss and noise considerations. Optimal number of estimated channels is presented for a dense scenario comprising 500 RRHs orchestrated by a DVS/CU element.	Improved user QoE and simplify user device. Improved flexibility and adaptability to different requirements. ~ 87% overhead length reduction for downlink training sequences under a dense DVS/CRAN deployment is achieved for different pathloss and number of estimated channels.
Cloud RAN Split options	Analysis of relevant split options tailored to the type of scenario (megacities and undeserved areas). The Low Layer Split (Option 7) is most suitable for Megacities scenarios. The High Layer Split (Option 2, or even Option 1) is more suitable for Underserved Areas.	Improved network availability Improved service retainability Improved transport network utilization

3.2.4 Development of dynamic mechanisms for multi-link/multi-node connectivity

This sub-task is focused on the most promising Multi-Channel Access (MCA) solutions for the 5G New Radio (NR) multi-service scenario, namely dual/multi-connectivity (DC/MC) and carrier aggregation (CA). In this context, solutions for URLLC and eMBB services have been proposed.

5G NR URLLC support defined in Release 15 comprises a set of features to ensure the stringent reliability and latency targets. PDCP-level packet duplication is one such important feature. However, the improved performance is obtained at the expense of an increased number of transmissions in the network, and, consequently, an increase in cell load, interference level and queueing delays. Furthermore, the additional resources used for duplication are unnecessary most of the times, i.e. when the primary transmissions are successful. To cope with this challenge, various mechanisms to increase the radio-resource efficiency of packet duplication have been developed. One of them is a network discard mechanism that relies on a novel UE duplication status report. This mechanism also provides a novel signalling framework to convey additional information between the network entities to significantly reduce the total amount of packet duplicates transmitted to the UE. The use of these techniques allows to improve integrity KQI (i.e., latency and reliability) while reducing the amount of resources used for duplicated packets.

Regarding eMBB services, two mechanisms to manage the secondary cells in a multi-connectivity scenario are proposed. Although it is presented in the light of maximizing the throughput of eMBB services, for which the data flow is split among the assigned CCs, it could be applicable to the URLLC case as well, where the data flow would be duplicated for reliability purposes. One of the proposed algorithms aims at determining the number and indices of CCs to be assigned to a specific UE, as well as the gNB(s) providing them, according to specific optimization objective(s) (e.g., maximize throughput, load balancing among CCs, etc.). Once the CC assignment is carried out, the second method determines the traffic flow that should be served by each CC. The target of the proposed solution is to find an enhanced traffic distribution with small signalling overhead that outperforms a conventional homogeneous traffic distribution. In addition to an improvement of throughput, it is possible to achieve a gain in quality of experience of more than 70% when using the automatic CC selection algorithm and a gain of more than 50% by using the split traffic algorithm.

The following table presents more details about the proposed solutions in the context of multi-link/multi-node connectivity and the obtained results.

Table 3-4 - Summary of key recommendations for multi-link/multi-node optimizations.

Feature	Recommendation	E2E / KQI benefits
Multi-legs configuration	It is proposed to estimate the achievable latency/reliability from the different “legs” which can be used to improve the reliability when sending up to 2 copies at a time.	Achieves optimal use of resources from the different component carriers, thus improving the KQI service integrity (i.e. tail of latency and reliability KPI) of URLLC traffic.
Operation for PDCP duplication for URLLC	It is proposed to use a) a novel duplication status UE report to	Significant reduction of resources used for duplicated

service classes.	timely acknowledge reception of a PDCP packet to multiple nodes, thus enabling in-network discard; b) selective duplication upon failure of the first packet transmission, thus avoiding duplicating when not necessary; and c) differentiating scheduling at the secondary node to avoid queuing delay for other traffic than URLLC.	packets can be achieved, which results in substantial improvement in the KQI service integrity (i.e. tail of latency and reliability KPI) of URLLC traffic.
Automatic allocation of CCs to a UE.	The usage of a rule-based system whose rules use both quality (RSRQ) and load metrics is recommended.	Results show up to a 100% gain for the users experiencing the worst throughput values over the state-of-the-art RSRP-based solution, and up to 75% throughput gain at the peak throughput. Also, an average MOS gain of more than 70% compared to baseline is obtained.
Smart traffic distribution in a multi-connectivity scenario.	Exploit the benefits of an uneven traffic flow split in a multi-connectivity enabled scenario, by making the split rate depend on both the signal quality (RSRQ) reported by the UE over the CC(s) being used and their current load. A rule-based system based on these metrics is recommended.	Results show a significant gain in both the 5th and the 50th percentiles for the UE throughput when compared to a situation of equally split traffic flows. Using the Uneven Traffic Split method, it is possible to achieve gains between 50% and 10% of the MOS for different services regarding the baseline.

3.2.5 Dynamic spectrum aggregation mechanisms, considering both licensed and unlicensed band usage

Several of the E2E performance enhancements proposed in the project encompass techniques based on dynamic spectrum aggregation. The incorporation of new licensed and unlicensed bands known as 5G New Radio opens the door to multiple innovations in this aspect. In this way, new strategies have been proposed for the allocation of radio resources based on multicell prescheduling. Additionally, it is also proposed the use of Bandwidth Parts (BWP) for the allocation of radio resources that allows the differentiation of services in 5G. With respect to the unlicensed band, improvements in signalling are included for use in conjunction with licensed bands (LAA) that allow optimizing the user experience in eMBB services (video streaming and FTP). Also, new bands expected to be used for 5G are evaluated from a service mapping view. Later, different requirements to be reached by the unlicensed bands operation and service provision are analyzed. Subsequently, a standard of independent unlicensed operation (Multefire) is optimized focusing on URLLC services. Finally, the possibilities of the non-licensed band in standalone mode for use in applications requiring low latency are analyzed, proposing possible improvements for future standards and identifying the challenges to be overcome. The conjunction of all these proposals offers a broad overview of the use of new spectrum aggregation techniques that will allow an improved service performance.

Table 3-5 - Summary of key recommendations and benefits spectrum related enhancements.

Feature	Recommendation	E2E / KQI benefits
Radio resource allocation strategies for services mapping	In a heterogeneous scenario, use a multi-cell aggregation scheduler (MAS) which, relying on the UE's CSI, determines what cell allows spectral efficiency and delay to be optimized when a UE is attached to it.	Improvement of E2E throughput and delay.
Dynamic spectrum aggregation for 5G new radio	Use dynamic bandwidth parts with/without the same central frequency for bandwidth adaptation and load balancing purposes, respectively.	Improvement of E2E throughput and delay (integrity).
LAA signaling assessment of eMBB services in unlicensed band (5Ghz)	Use DRS 160ms periodicity Activate DRS compensation method (CDRS) when disabling DRS signals Automatic per service and load conditions priorities selection	Results show an improvement of both FTP KQI service integrity indicators with respect to any other selected DRS periodicity defined by the 3GPP standard. In indoor ultra-dense scenarios up to 40% improvements in File Transfer Delay and 5% File Transfer Throughput while improving fairness in 15% towards WiFi.
Unlicensed standalone operation with MF	Achieving low latency communication in the 5 GHz unlicensed band is challenging due to the LBT procedures. For the uplink, GUL is recommended for low latency traffic over SUL.	Results show that use cases requiring one-way radio latency in the order of 30-40 ms with 99.9% reliability can be supported in the 5GHz band with MF. Using grant-free uplink transmissions offers 25% latency improvement at low to medium loads. Enabling

		K-repetition for ACK/NACK feedback gives ~20% latency improvement at low to medium loads. Omitting Cat 1 LBT during DL-2-UL transition results in up to 55% latency improvement when the offered load is high.
NR-U standalone	NR-U offers significant latency/reliability benefits as compared to MF due to shorter TTIs, more flexible frame structure, reduced gNB and UE processing times. But, LBT procedures still limit the latency budget.	Latencies of 8-17ms at 99.99% reliability can be supported in the 5GHz band with NR-U.

3.2.6 Advanced mobility optimization and fast agile load balancing mechanisms

The present sub-task is dedicated to the key developments revolving mobility optimizations and load balancing techniques. Here, a special focus has been placed to establish approaches going beyond classic KPI-based control, adopting an E2E view of the network supported by novel predictive techniques. This translates in the use of QoE/KQIs as well as context-information (e.g. position, social data) in order to guide the optimization of future 5G networks. Also, the challenges introduced by 5G services, small-cell and V2X deployments are addressed.

In the context of load balancing, a first study has confirmed how traditional load balancing techniques methods may have an undesirable impact on the QoE for different services. Based on this result, a novel QoE balancing algorithm has been proposed to achieve a QoE equilibrium among cells.

In the line of context-awareness, information related to social-events (e.g. concerts, parades, etc. start time and location) has been integrated for the management of the cellular network, supporting both prediction of future performance and load-balancing techniques to avoid peak-demand related degradations. Advanced forecasting mechanisms of the users QoE have been also adopted in order to lead predictive optimizations. In terms of small-cell mobility, predictive network control (PNC) strategies have shown improved network performance for URLLC services. In network-slicing scenarios, mobility and traffic patterns (e.g. daily profiles in user densities and demand) have been also applied to guide improved allocation of spectrum between different areas at different times.

In V2X URLLC scenarios, both MEC-assisted communications and the management of RRC Idle and RRC Inactive states have been identified as enablers for successfully achieving their stringent delay requirements.

In terms of basic 5G NR features, RA-less handover, network assisted UE secondary cell management and multi-node connectivity are identified as means for improving mobility, while service-based conditional handovers can be used to improve service KQIs.

Table 3-6 - Summary of key recommendations and benefits for mobility optimizations.

Feature	Recommendation	E2E / KQI benefits
QoE balancing algorithm	QoE equilibrium can be achieved by tuning HOM between cells	QoE balance scenario for services such as FTP, Video, VoIP and HTTP.
Social events information gathering, association and application to cellular networks	Social data is required to properly forecast and avoid service degradations	The increases in demand related to events highly impact the service provision. Social-aware optimization mechanisms allow for detecting social events as the cause of past degradations, forecasting of future increases of demand and load-balancing mechanisms allowing a 44% reduction in the peak increment of users served by the site closest to the venue.
QoE proactive management	Use a predictive framework for network performance forecast, so that occasional performance issues leading to UE's QoE degradation can be avoided by means of a proactive network configuration.	All the E2E KQIs can benefit from this research line. Especially integrity-related KQIs such as the E2E throughput.
Algorithm on mobility and access management	Use channel quality (CQI) measurements, location information and availability of connection to a cell to drive users' mobility	Improvement of E2E throughput and delay (integrity).
Utilization of Prediction in Small-Cell Mobility	PNC controlled strategy to forward PDCP PDUs in a MC connectivity scenario with a split bearer architecture. The PNC strategy will be based on periodic CSI reports captured in the PDCP layer in the MgNB which is acting as the base	Gains of 10% of throughput during the execution of a SCell change process in an URLLC client performing a detected trajectory over a set of SmallCells.

	station for the primary cell (PCell).	
RRC State Selection for URLLC V2X	Exploitation of RRC Idle and RRC Inactive states for V2X applications	The increased number of devices impacts the V2X applications with strict delay requirements. The use of platoons and different RRC states can be used to allow for more non-V2X devices to be served, while respecting the stringent delay requirements of V2X.
MEC-assisted C-V2X Communications	Exploitation of MEC deployments, where edge hosts are co-located with radio connectivity nodes.	E2E latency reduction, as compared to “legacy” network architecture; such a reduction can be proven life-saving for critical scenarios such as the one of VRU.
Basic 5G NR mobility solutions	Use synchronous RA-less handovers. Use network-assisted UE autonomous secondary cell management. Use multi-node connectivity when feasible for achieving zero handover interruption times and enhanced robustness. Conditional handovers for selected services.	Offers reduced handover interruption times, enhanced mobility robustness with low HOF and RLF rates, and reduced signaling (RRC, RA, and Xn) overhead. Maps to improvements in KQI service retainability and service integrity.

3.2.7 Connectivity optimizations for device-to-device communications and relaying paths

In this sub-task, the results and recommendations related to D2D communications are commented. D2D are considered an efficient technique to offload traffic in a market where the number of connected devices and the demand for data rates is increasing exponentially. It is also an enabler for mMTC applications, where it can optimize resource allocation and power consumption.

Firstly, a resource optimization scheme in a heterogeneous network was investigated, comprising both D2D and non-D2D users. The objective is to develop a distributed scheduling scheme that is both throughput optimal and energy efficient. The proposed scheme is based on CSMA, with devices having the ability of switching between a SLEEP and AWAKE mode dictated by a timer. An optimization problem involving the sleep and the CSMA backoff timer was formulated and tested, showing that it can be solved in a distributed manner where each node in the network simply monitors its past service rate and awake duration. At the optimal point, the throughput requirement of each node is satisfied and nodes wake-up just as needed.

In second place, the problem of power minimization in a dense MTC network was undertaken. A simple threshold-based policy was implemented in a distributed manner, taking into consideration the dynamic activity (queue state information) of the MTC and wireless channel conditions (channel state information) and reducing the signaling overhead. This is achieved by using a binary power control, which is simple to implement in practice with low signaling overhead, can achieve a tradeoff between energy consumption and average delay in the scenario where the traffic arrival is low and for Gilbert-Eliot channel model.

The use of D2D communications as a cooperative scheme to enhance downlink communication for eMBB was also explored. Two solutions were compared; the first one with relay selection at the BS, and a second one with distributed relay selection where the decision is done at the user side. With some limited feedback on the state of the queue stability of the users and the CSI available to the users, it is shown that the distributed scheme outperforms the centralized one.

Finally, the problem of D2D autonomous resource allocation is explored, finding that Automatic Repeat Request (ARQ) and Hybrid ARQ with Chase Combining (CC-HARQ) schemes improve the reliability without increasing the complexity of the MTDs. From an energy consumption point of view, it is found that, in scenarios with high density of MTDs, CC-HARQ outperforms ARQ, resulting in an overall more energy efficient solution. To reduce complexity, it is proposed to join discovery and relay selection using a proposed RR/RC protocol. It is shown that when the data packet size is large when compared to the discovery packet size, and the MTD is far from the cellular BS, D2D reduces the energy consumption significantly.

Table 3-7 - Summary of key recommendations and benefits for D2D optimizations.

Feature	Recommendation	E2E / KQI benefits
Stochastic resource optimization for heterogeneous architecture	The optimal distributed scheduling that achieves a trade-off between total throughput and energy consumption can be obtained by an appropriate modification of the CSMA/CA.	3-5 times less power consumption in average, improvement of E2E throughput.
Power consumption reduction for mMTC	Binary power control (i.e. on/off with max power) achieves a trade-off between minimizing power consumption and average delay for low traffic arrival and Gilbert-Eliot	Improvement of latency by 10% and service retainability (battery life).

	channel.	
D2D relaying for eMBB	In the scenario of limited CSI feedback, relay selection made at the user side achieves a better queuing stability region as compared to the case where the relay selection is made by the BS.	Improved queuing stability, which results in improved E2E throughput, by 25%.
D2D relay mechanism for mMTC services	Use the autonomous resource allocation mode and consider using CC-HARQ as retransmission scheme to take care of interference and increase the transmission success probability Use our RR/RC protocol as low complexity D2D discovery protocol	Optimization of resource allocation Optimization of the energy consumption (up to 50% gain for 200 bytes packet size and devices located beyond 500 m from the BS) Low complexity for the MTC device Improved KQIs network accessibility and service retainability (battery life)

3.3 Multi-antenna access and link enhancement

This section summarizes the results of work package WP4- The three main objectives of WP4 are as follows:

- Develop future-proof multi-service access solutions for mMTC and URLLC.
- Develop massive MIMO enablers towards practical implementation.
- Develop advanced link management solutions for interference coordination and avoidance, based on the assumption of CRAN/DRAN deployments and/or massive MIMO.

For each of these three objectives, a respective task has been defined within WP4. The overall objective is the development of link-specific techniques (mostly PHY/MAC) for the 5G long-term evolution. Our approach consists of a mixture of analytical work, the development of advanced hardware models, as well as numerical simulations (mostly link level, but also system level). Throughout the project, WP4 has followed the standardization work in 3GPP and the work plan was aligned correspondingly. Many of the WP4 results are included in technical contributions to 3GPP (see Section 3.5.3 and the detailed explanations in the final deliverable [D4.2].

In the following, we will summarize the WP4 key achievements, recommendations, and benefits. For more details, we refer to [D4.2] and also to the publications being produced by the partners (also referenced in [D4.2]).

3.3.1 Future-proof multi-service access solutions for mMTC and URLLC

Task T4.1 develops solutions that support the growing demand of multi-service mobile communication from vertical sectors such as Factories of the Future, Automotive, Smart Cities, Energy and others. The 5G NR standard has introduced two new service classes, namely URLLC and mMTC. URLLC services target highly reliable communication with very low latencies, whereas mMTC services supports the growing Internet-of-Things (IoT) applications characterized by a very large number of low-cost devices operating with sporadic traffic over limited spectral resources

Design of reliable signalling schemes and low-overhead natively-secure access protocols

URLLC has been introduced in 3GPP Rel. 15, targeting highly reliable and very fast communication of typically short packets [TR38.913]. The basic features include TTI structures for low latency as well as methods for improved reliability. In Rel. 16 [3GPP-38.824] further use cases (factory automation, transport industry and electrical power distribution) with tighter requirements have been identified for the NR evolution.

ONE5G has developed enhancements for increasing the overall URLLC load for uplink grant free (configured grant) transmission where radio resources are shared among

multiple users, such that collisions can happen. Grant free access is proposed as a key technology for reducing the access latency. The targeted ONE5G use cases are: UC1 “Assisted, cooperative and tele-operated driving (between vehicles, and between them and infrastructure)”, and UC2 “Time-critical factory processes and logistics optimization (industry and smart airports)”.
Another important aspect addressed by ONE5G is the improvement of reliability for massive MTC scenarios. This is mainly targeting non-time-critical use cases such as ONE5G UC4, UC7, and UC8 (factories, smart cities, e-health, smart grids).

Table 3-8 - Summary of key recommendations and benefits for reliable signalling schemes and low-overhead natively-secure access protocols

Feature	Recommendation	Link performance/KPI benefits
URLLC Uplink Grant Free Access	RRM principles for GF: 1) GF URLLC should be aided by mini-slot repetitions and HARQ with short RTT. 2) For periodic traffic, dedicated resources can be used for initial transmission and shared resources for repetitions, aided by SIC. 3) To improve outage capacity for sporadic URLLC, use full pathloss compensation, optimized P0 and robust MCS adapted based on coupling gain. 4) GF URLLC and eMBB can use overlaying allocations when employing MMSE+SIC and for low URLLC load, while separate resources should be used for stricter URLLC requirements.	The proposed grant-free design enables URLLC with improved resource utilization compared with Rel-15. For deterministic traffic, the shared retransmission scheme leads to 23% improvement in resource efficiency. Power boosting retransmission allows at least 20% higher outage capacity in UMa. The use of multiple GF configurations with multiple MCS shows ~90% higher achievable load for URLLC. And the multiplexing of eMBB and URLLC using overlaying allocation allows to reach almost 100% resource utilization compared with ~35% if the bandwidth part is only used for sporadic URLLC.
Preamble Detection using Multiple Base Stations	Centralized preamble detection schemes can be exploited to improve detection performance. The Quantize-and-Forward scheme is preferable over the Detect-and-Forward scheme in deployments where a number of BSs are at approximately the same distance to the UE so that the same quantization steps are applicable for all BSs and as long as the backhaul capacity is sufficient.	The schemes improve detection reliability, hereby lowering access latency. In our simulation study we found that three orders of magnitude in improved missed detection probability was achievable with the use of 20 and 25 base stations for the QnF and DnF detection schemes, respectively.
Advanced Beamforming Designs to Enable New Services and Network Functionalities	Large antenna arrays at the BS are assumed, and a technique consisting in refining the instantaneous channel estimation based on the long-term channel structure is proposed. The trade-off between how many training symbols are required for each scheme is	Utilizing the channel structure when performing coherent beamforming provides higher reliability (up to two orders of magnitude compared to MRT not utilizing it) in the single user case. For multi-user, zero-forcing outperforms TDMA with coherent BF

	shown in an URLLC context.	and second order statistics.
Interference Mitigation for Bi-Directional URLLC	The proposed bi-directional frame design based on adjacent-channel full duplex allows for flexible duplexing of radio resources in both time and frequency.	A precoding scheme is proposed which achieves suppression of OOB emissions by around 100 dB compared to the non precoded solution for adjacent channel full duplex
HARQ Investigations regarding URLLC	3GPP LDPC codes may be used for URLLC, but the current base graphs are not optimized for very low code rates demanded. Moreover, when investigating URLLC, it may be advisable to do that in a complete system level and link level tool, allowing to simulate all effects dealing with such high reliability requirements.	Investigation of HARQ performance with current codes, providing insights on performance with multiple CC and IR schemes, and their sensitivity with respect to all MCS parameters: CC-SLC seems preferable to IR (similar performance with low code rates, but lower complexity) and to CC-BLC. The gain is up to 1.2 dB.
Short Packet Transmission with Reliability-Latency Constraints	The throughput under reliability-latency constraints is investigated in this work item. Since short packet transmissions are considered, the grant-free scenario is considered, and the number of arrived users or the arrival distribution are used in order to maximize the throughput.	Increasing the superslot size K has been noticed to improve the reliability. The results also point out that the throughput can be improved if the knowledge of arriving packets can be accurately estimated. For instance, in the case of 15 active users, increasing K from 5 to 10 provides roughly an improvement of two orders of magnitude in reliability. Moreover, even if there is a considerable estimation error, when high reliability is targeted, the throughput performance still improves.
Reliable Schemes for Short-Packet-Transmission in Massive MTC	In the mMTC scenario with sporadic transmission of short messages, reliable operation can be achieved by sparse superposition coding and receiver diversity (C-RAN architecture), in combination with advanced Bayesian receivers. Architectural constraints in the form of fronthaul limitations should be accounted for.	The transmission scheme trades the number of users that can be simultaneously supported with the message length. When the messages are short, the number of simultaneously active users that can be supported is 2-5 times higher than the one typically considered in mMTC simulations. In the CRAN scenario, the advanced Bayesian receiver yields higher reliability (up to an order of magnitude) when compared to simpler, correlation based receiver.

Design of non-orthogonal multiple access (NOMA) and code design

Even though the NOMA standardization in 3GPP is currently on hold because of other priorities, the following results show that the NOMA design principle has a wide range of benefits ranging from eMBB to URLLC and short-packet mMTC services. ONE5G has developed enhanced NOMA techniques for increasing the number of supported

devices per cell, which is particularly important for mMTC. Our approach includes regular spreading matrices, spatial preamble reuse, and reinforcement learning for preamble selection. Also, we propose NOMA for service coexistence, particularly for sharing resources between different service types, e.g. eMBB and URLLC.
NOMA has a wide range of potential applications, especially for industrial and massive IoT services. But also eMBB services can benefit from NOMA.

Table 3-9 - Summary of key recommendations and benefits for non-orthogonal multiple access (NOMA) and code design

Feature	Recommendation	Link performance/KPI benefits
Link Level Comparison of NOMA solutions	Both NOCA and IDMA are appropriate for mMTC type traffic. Both NOMA schemes allow relaxed scheduling and control.	NOCA is low-complexity. It supports random user-specific spreading codes selection and exhibits high robustness against user signature collision. IDMA is with increased but affordable complexity. It can support asynchronous communication. Comparing to the 3GPP Release 15, one of the most important benefits of NOCA and IDMA is that the supported user number can be 5 to 10-fold. NOCA can typically achieve 250% overloading and IDMA can achieve even higher overloading for asynchronous traffic.
Non-Orthogonal Multiple Access and Code Design	Low-density spreading NOMA with iterative near-optimal multiuser detection benefit from structure of the underlying factor graph. We propose a flexible (regular-sparse) code construction.	The proposed signature design allows to flexible trade different QoS requirements at high overload (more than 250% compared to 3GPP Rel. 15) with low-complex receiver architectures.
Contention based Uplink NOMA transmission	SIC-based NOMA approached can benefit from splitting the coverage area in different zones and re-using the preambles among those zones. Further improvements can be achieved when RL is used for preamble selection.	Our scheme decreases the number of collisions in the RACH by ~ 30%, and the network access delay by ~ 57%, compared to the RA process with NORA of Rel. 15.
Enhanced Grant-Free Access with Advanced Receiver	Grant-free access reduces the delay for URLLC and signalling overhead for mMTC. We propose to use a block-wise sparse NOMA scheme to mitigate the interference caused by packet collisions.	Block-wise sparse NOMA based on low-rate channel codes can more than double the supported system load compared to conventional coded random access schemes based on packet repetitions and slot-wise decoding.
NOMA multiservice underlay communication	Superposing eMBB and mMTC on the same resources can be performed by superposing two sets of orthogonal waveforms, namely	Our results show that the proposed multiservice NOMA scheme with ML detection allows superposing MTC and eMBB services on the same resources, by

	OFDMA as the first signal set and MC-CDMA as the second signal set,	achieving a channel overload factor of 25%. This helps increasing the number of served MTC devices by 25%.

3.3.2 Massive MIMO enablers towards practical implementation

The objective of T4.2 is to reduce the gap between theoretical MIMO work and the application of massive MIMO in real world scenarios.

Massive MIMO enabling technologies

This research activity investigates novel technologies for beam management, distributed beamforming, beamforming for flexible access and backhaul, as well as optimized array formats and capacity analysis. Beamforming is crucial for the operation in higher frequency bands (mmWave) in order to compensate the path loss. ONE5G has developed various strategy for a more flexible connectivity, including new concepts like multicast beamforming, and interference-aware beamforming for integrated backhaul. Also, ONE5G has analyzed the system performance when using different types of antenna arrays, namely Uniform Planar Arrays (UPAs) and Uniform Cylindrical Arrays (UCAs).
The main focus is on the Megacity scenario, e.g. UC5 "Outdoor hotspots and smart offices with AR/VR and media applications" as well as UC6 "Live Event Experience". But also "Underserved Areas" benefit from beamforming (SNR improvements).

Table 3-10 Summary of key recommendations and benefits for massive MIMO enabling technologies

Feature	Recommendation	Link performance/KPI benefits
Multicast Massive MIMO	ONE5G recommends the use of beamforming based MIMO-multicast for group-wise transmission to spatially distributed UEs instead of time-shared unicast, at least in the "V2X" and "IoT" use cases (both industrial and mMTC).	The achievable multicast gains depend on the UE distribution and also on the number of UEs. It was shown that the throughput can be increased many times over.
Wireless backhaul for coverage enhancement in low ARPU network	ONE5G proposes a new precoding scheme for wireless backhaul link which takes into consideration also the potential interference coming from an independent but parallel access link. We call this scheme RZF-CI in short.	The RZF-CI precoding scheme, as shown in D4.1, can provide better (up to 8 dB) link budget in terms of received SNR for wireless backhaul link compared to ZF precoding. At the same time, the loss is limited to less than 1.5 dB compared to the ideal MRT precoding. It is also confirmed in D4.2 that the performance is stable in both synchronized and non-synchronized situation between backhaul and access

		links. Thus, the RZF-CI scheme can enable cost reduction for the deployment
Signal Shaping for MIMO Backhaul Channels	Signal Shaping can improve the coded modulation performance for high order modulation for AWGN and fading channels, also in high throughput scenarios and short transmission frames.	Shaping achieves 1dB SNR gain. By reducing the sequence length, parallel processing of 5 sequences is facilitated without performance degradation. This leads to higher throughput and lower latency of the shaping encoder by a factor 5 compared to the state-of-art Constant Composition Distribution Matcher.
Beamforming Design and Function Split for Partially Centralized RAN with Massive MIMO RRH	The purpose of CRAN architecture is to keep minimal functionality at the RRH in order to i) benefit costs and scalability, ii) alleviate transport between RRHs and BBU, and iii) facilitate CSI acquisition. This can be done by performing analogue beamforming at the RRHs, based on second order statistics estimated at the BBU. The low-dimensional CSI observed through analogue beamforming is then employed for digital beamforming at the BBU.	The proposed scheme decreases the complexity due to reduction of RF chains and due to the smaller number of instantaneous channel coefficients to be estimated. However, it incurs a performance degradation in terms of sum-rate compared to a fully digital implementation, which can range between 4-16% for the case of 16 active RF chains.
Beamforming Algorithms for System Utility Optimization toward Massive MIMO	With partial CSIT under the sum rate optimization (SRO), we should take into account the channel estimation and the estimation error covariance together to make the beamforming design; and we can also use the local pathwise CSIT. For the user rate balancing, a new proposed matrix-weighted user MSE approach provides beamforming expressions for MU-MIMO.	With partial CSIT under SRO, the sum rate versus SNR performance has not a saturation floor with increase of SNR contrary to others existing techniques; by using the local pathwise CSIT, the CSIT acquisition can slow down with limited spectral efficiency loss. For the user rate balancing, the balanced rate outperforms the minimum rate obtained by user MSE balancing of 15% with 15dB; and the implementation on software or HW of our algorithm is straightforward.
Joint Investigation of UL Channel Estimation and MIMO Detection Regarding Robustness	In the case of severe non-linearities of the analog front-end, always jointly (UL channel estimation and MIMO detection) design the receiver signal processing architecture.	Reduced computational complexity. Gain of about 20 % relative to linear receiver.
Channel Quality Estimation Sequence Design for Beam Management	Optimize the beam-training sequence length and as well as beam-training interval to adapt to the communication requirements.	Beam-training overhead is minimized. Gain of up to 40 % relative to 802.11 ad beam training procedure possible.

Impact of Array Format in Different Deployments	With massive MIMO, the shape of the BS array must be adapted to the deployment scenarios and to the UE distribution.	In UMa (probably the most relevant scenario for massive MIMO) wide arrays strongly outperform tall arrays: for instance, a 1x32x2 array provides a gain up to 7 dB when compared to a 8x4x2 array in the median of the UE SINR.
Sector and Beam Management with Cylindrical Antennas	Widely used UPAs, e.g. in 3GPP, are not the best antenna deployment for some use-cases or scenarios. With massive MIMO, ONE5G recommends a use-case customized design of antenna deployments to achieve desired target KPIs for both cellular and non-cellular scenarios.	In single BS scenario the UCA provides a more homogeneous SNR/SINR in the horizontal-plane and improves reliability (5 % user throughput) compared to state-of-the-art (3GPP) sectorized uniform planar array (UPAs) by approximately 15 %. In multiple BS scenario (SLS) the average SNR is increased by 3 dB.
MIMO Performance Prediction	State of the art formulas for SNR variations prediction doesn't work well when considering realistic propagation scenarios. We introduced a new formula that accurately measures the variations of the SNR depending on both antenna array topologies and environment.	Up to 4 times gain in SNR variations prediction accuracy in simulated scenario over baseline correlation matrix approach. SNR is a key input for scheduling and resource allocation at system level. Accurate prediction of the variations of the SNR can enhance scheduling choices.

Optimized implementation for scalable and flexible support of multiple services

This activity is focused on efficient hardware implementation, hybrid array designs, as well as the flexible implementation of forward error correction. For future mmWave systems, the power consumption is a major challenge for both device and access point. The successful deployment of truly massive arrays will depend on the development of new power-efficient implementations. Also, a flexible signal processing architecture will be needed in order to support the requirements of all services with a single hardware. The ONE5G results are mainly relevant for Megacity use cases.

Table 3-11 - Summary of key recommendations and benefits for Optimized implementation for scalable and flexible support of multiple services

Feature	Recommendation	Link performance/KPI benefits
Hybrid Array Architectures for Different Deployment Scenarios	Flexible adaptation of array shape and size according to variations in deployment and traffic load conditions.	Increased energy efficiency for massive MIMO operation in varying load conditions, applicable to various deployment scenarios. More than 60% energy saving compared to full size array in low load conditions possible.
Flexible and Fast Reconfigurable HW Architecture for Multi-	Flexible hardware component is required to address a 5G Real time communication which addresses	The component runs on FPGA at 250MHz. Near antennas, the DFE handles IQ samples with a reduced

Service Transmission	several services, with no disturbance. Developed algorithms take into account each service's specification.	processing latency. The loopback Transmission / Reception is processed in 20 µs. The upper layer receiver, containing generic mapping and FEC deals with variable packets length for up to 300 Mbps. Thanks to pipelining, the context switches from 8 ns (when the block is unoccupied) to 524 ns (when emptying pipelines). Services are deserved in a transparent way to the user. Mutualization of the HW architecture for multiple services preserves HW resources by factor 2/3 with equivalent throughput and latency as dedicated one.
Genetic Algorithm Assisted Hybrid Beamforming for Wireless Fronthaul	To reduce hardware cost, it is recommended to deploy low-resolution limited-RF-chain hybrid beamforming antenna arrays with the proposed algorithm to wireless backhaul and fronthaul. Future research and development directions can include hardware implementation.	In SNR regime -15dB to 0dB, 2-bit resolution phase shifters can achieve 93% of fully digital beamforming performance. In SNR regime 5dB to 15dB, 2-bit resolution phase shifters can achieve 95% of fully digital beamforming performance.
A Comparison of Hybrid Beamforming and Digital Beamforming with Low-Resolution ADC's for Multiple Users and Imperfect CSI	As our evaluation showed that especially in the low per antenna SNR region the digital beamforming system has substantial spectral and energy efficiency benefits, this system architecture should also be considered for future mmWave communication systems.	Improved energy efficiency or coverage. Gain of 50 % relative to hybrid beamforming solutions.

Advanced pilot and feedback design for massive MIMO

CSI acquisition is a bottleneck for advanced multiuser massive MIMO. While massive MIMO provides high multiplexing gain, its performance critically depends on acquiring accurate CSI at the transmitter, which is then used to encode the transmitting signals and null the interference at the receivers. ONE5G has developed efficient pilot and feedback schemes for CSI acquisition with reduced overhead, as well as strategies for pilot contamination mitigation. The results are mainly relevant for Megacity use cases.

Table 3-12 - Summary of key recommendations and benefits for advanced pilot and feedback design for m-MIMO

Feature	Recommendation	Link performance/KPI benefits
TDD: Improving CSI Acquisition through Spatial multiplexing	Clustering the users according to their spatial signatures and allocating the pilots to the formed clusters using the proposed spatial basis coverage allocation provides a huge performance improvement.	Results show that one can increase the spectral efficiency by 2/3 with respect to a baseline massive MIMO (with no interference management, random pilot assignment, pilot reuse in all cells).
FDD/ Improving CSI Acquisition through Spatial multiplexing	Grouping the users according to their channel covariance matrices and scheduling the groups for CSI feedback allows achieving a tremendous gain in network throughput	Results show that the achieved throughput can be doubled as compared to a baseline from [D4.2] conventional massive MIMO (with no interference management).
Pilot Allocation taking into account Markovian Channel Model and Traffic Patterns	Scheduling the users for CSI acquisition taking into account the channel time correlation and the traffic arrival achieves an important performance gain.	Results show that one can increase the spectral efficiency by 14% with respect to a baseline from [D4.2] massive MIMO where all users transmit their pilots all the time
Fractional Power Control to Mitigate Pilot Contamination in 5G Massive MIMO	Uplink FPC is fundamental to mitigate pilot contamination in massive MIMO systems.	Very high gains (up to 350%) can be achieved in the cell border throughput by using FPC when compared to noPC.
Parametric Channel Estimation for Massive MIMO	Using a physical description of the channel is beneficial for efficient channel estimation. It is possible to generalize steering vectors to take into account very large antenna arrays close to the users.	In average 40% decrease in mean squared error (MSE) compared to the classical least squares method and to the plane wave model in an urban microcell environment with an ULA of 256 antennas on a building (at a height of 5 meters) and users randomly located in the adjacent street.
Hierarchical Sparse Channel Estimation for Multiuser Massive MIMO with Reduced Training Overhead	Training overhead reduction of uplink multiuser massive MIMO can be achieved via a sophisticated training design and computationally efficient channel estimation algorithms exploiting the hierarchical sparsity of the wireless channels.	For an asymptotically large number of antennas and bandwidth, the proposed algorithm achieves reliable channel estimation with a bandwidth overhead that is almost an order of magnitude smaller than that required by conventional approaches and is independent of the number of propagation paths (per user).
Wideband Massive MIMO Channel Estimation via Atomic Norm Minimization	For operational conditions with a limited number of propagation paths (e.g., mmWave communications), superresolution techniques such as atomic norm minimization can be applied to achieve near-optimal and	Compared to standard LMMSE channel estimation and for a very sparse channel (3 paths), the proposed algorithm provides a channel estimate MSE that is orders of magnitude smaller and with less than 50% of the training overhead.

	low-overhead channel estimation in uplink massive MIMO.	
On the amount of DL training in correlated massive MIMO channels	Careful design of training sequences and their number according to the operating SNR and the channel (spatial) covariance may significantly reduce the DL training overhead in FDD multiuser (massive) MIMO scenarios. A small number of fed back channel covariance eigenvectors from the user to the BS helps the latter in this design.	Proposed scheme results in accurate channel estimates but with a large reduction in training overhead. This translates to larger effective throughput gains. Exact reduction depends on the covariance structure and number of users, but for typical covariance matrices and number of served users, the training overhead reduction can exceed 50% compared to state of the art methods.
Efficient Feedback Schemes for more Accurate CSI and Advanced Precoding	Explicit time domain based CSI feedback can provide forward compatibility to advanced MIMO concepts in future releases. In addition, due to the time domain sparsity, better overhead reduction can be achieved with time domain compression.	Proposed time domain based explicit CSI feedback scheme can achieve 8% higher spectral efficiency compared to Rel. 15 NR type II CSI while saving 16% of the UL overhead.

3.3.3 Advanced link management solutions for interference coordination and avoidance, based on the assumption of CRAN/DRAN deployments and/or massive MIMO

Task 4.3 has developed sophisticated signalling and scheduling schemes for CRAN/DRAN deployments. This is motivated by the dense network infrastructure expected for "*Megacity*" scenarios as well as advancements in cloud computing.

Advanced node collaboration and link state prediction

This activity is focused on the development of novel techniques for interference management in CRAN and also cell-less communications.

For massive-MIMO enabled cell-less systems, novel scheduling schemes based on user grouping were developed that result in a reduction of pilot contamination effects with low-complexity receiver processing (matched filtering). Algorithms for joint power control and UE-to-RRHs association were also developed. For the case of an overloaded system (more users than antennas), non-linear detectors are employed, which adapt to the non-stationarities of the environment via a machine learning approach, outperforming conventional (linear) detectors. The WP4 solutions offer significant gains compared to conventional (non-cooperative) massive MIMO. They suggest new signalling in order to implement the user grouping, pilot allocation, and adaptation of non-linear detectors, to be considered in future 3GPP releases (17 and beyond).

ONE5G develops enhanced interference management techniques for the interaction between underlay D2D and cellular users. Also, interference management solutions enabling IAB in NR, NR duplexing with CRAN and network coordination, as well as decentralized beamforming algorithms were proposed. Interference management solutions suggest new signaling in 3GPP. Part of our solutions has been contributed to the ongoing Rel-16 discussion on "multi-panel/massive MIMO"

Table 3-13 - Summary of key recommendations and benefits for dynamic mechanisms for advanced node collaboration and link state prediction

Feature	Recommendation	Link performance/KPI benefits
Centralized and Distributed Multi-Node Schedulers for Non-Coherent Joint Transmission	A distributed network architecture is sufficient to the majority of scenarios. Therefore, it is recommended to use a distributed network as baseline with the ability to switch between various distributed and centralized network coordination methods. How to efficiently switch between network coordination schemes will be an important issue in standardization, impacting the signalling design.	Simulations show that 36% performance median user downlink throughput gain with NF-NCJT over Rel-15 baseline (DPS).
NR duplexing with CRAN and network coordination	It is recommended to reduce cross-link interference in duplexing and IAB with the NR network coordination framework. This principle will significantly impact the NR standardization.	In sub-6 GHz (2GHz), the aggregate result is that the network with IAB still outperforms the network without in terms of downlink throughput (twice the median). In above-6 GHz (30 GHz), the network with IAB significantly outperforms the network without in terms of downlink throughput (28 times the median).
User and Resource Scheduling in Network Massive MIMO with underlay D2D	We developed a user and resource (AP) scheduling in network massive MIMO with underlay D2D. Results show that a fraction of APs must be used.	Results show that scheduling achieves a throughput gain of 20% as compared to the conventional scheme.
CSI Acquisition and Interference Management using Matrix Exponential Learning	We developed two CSI feedback schemes with reduced signalling information for distributed MIMO. Results show that, for the considered scenarios, sporadically transmitting a complete feedback for each user is a better strategy than always transmitting incomplete feedback.	The proposed reduced feedback schemes do not affect the convergence of the system to Nash Equilibrium but at a high convergence time. The methods are then useful in wireless networks with limited feedback.
User Scheduling in Cell-less Massive MIMO Systems	Improving the performance of Cell-free massive MIMO can be achieved through Location and large-scale fading based user grouping, along with optimizing access point assignment and pilot allocation.	Results show a throughput gain of 18% compared to conventional schemes.

Multi-connectivity beamforming for extreme reliability and multiple access	We develop a max-min strategy for equalizing the SINR distribution for cooperative multi-link beamforming and dynamic TRP association. The objective is the support of extreme reliability requirements for a large number of high-throughput users. Also, we avoid cell edge effects and achieve a more uniform distribution of capacity over the service area.	With respect to the baseline technology (conjugate beamforming) we observe a gain of around 4 dB for the 50th percentile. But more important is the reliability gain. We demonstrate that an interference-saturated scenario with 10% of users below -5dB can be turned into an equalized SINR distribution where all UEs achieve +5dB.
RRH selection for multicast communications in cell-less systems	RRH selection for joint multicast beamforming is difficult because it involves two coupled NP-hard problems. In Section 4.3.3., we showed that RRH selection can be decoupled from the optimization of the beamformers, by maximizing an upper bound on the achievable multicast capacity. This allows the application of submodular optimization methods (e.g. the SATURATE algorithm) for selecting the RRHs.	Simulations verify that the optimality gap of SATURATE for maximizing the upper bound is at most 0.7dB. Moreover, the multicast SNRs resulting from the subsequent beamformer optimization are only 1-2dB below this upper bound. The proposed method outperforms the naïve greedy approach by up to 8dB.
Nonlinear Mechanisms in Cell-Less Systems	It is known that increasing spatial diversity increases the reliability of a wireless uplink. So, cell-less systems powered by robust and low complexity detection methods are recommended in dynamic wireless environments that require high reliability. Also, nonlinear detection methods can help keep the number of antennas at the receivers small. Explicit channel estimation (and associated errors) can be avoided by using machine learning based methods.	Simulations show that by using our distributed framework, reliability performance (BER) can be improved by up to an order of magnitude 4 (over centralized solutions at the lowest fronthaul capacity) depending on the number of RRHs. The training set sizes can be reduced by more than 50% by employing multi-connectivity.
Centralized Scheduling for the Uplink Multiple Access Multiple Relay Channel (MAMRC)	In slow-fading orthogonal MAMRC with small number of sources, we recommend the use of IR-HARQ scheme with Single User encoding over the IR-HARQ with Multi User encoding and CC-HARQ schemes, as it offers the best trade-off between performance and complexity.	Average spectral efficiency that can be obtained using IR-HARQ with SU encoding, whose code construction is well mastered (rate compatible punctured codes), is close to the one provided with IR-HARQ with MU encoding, where iterative joint decoding is used (which is more complex), the coding loss being no larger than 1dB.

Efficient signaling and control for advanced connectivity

This activity is focused on CSI acquisition for CRAN and also functionality placement in service-oriented NFV RAN. The full potential of CRAN, enabled by advanced joint transmission and decoding, as well as network-wise resource allocation and scheduling, can only be achieved when accurate global CSI is available. However, for dense CRAN, the estimation and feedback of CSI becomes challenging. This is because the number of TRPs associated with each UE can potentially be much greater than one or two (as in the case of conventional cellular networks). This naturally implies a significantly increased number of channels that need to be accurately estimated, and, in turn, an increased overhead dedicated for channel training and feedback purposes. Additional overhead may also be introduced by measuring and tracking interference levels experienced at the receiver side for optimal link adaptation.

In NR Rel-15, several advancements have been implemented regarding CSI acquisition procedures such as improved feedback codebooks for MIMO channels [TS38.211] and the introduction of the quasi-co-location concept, which is particularly suited for network coordination/cooperation schemes [TS38.214]. However, even though Rel-15 specifications are, in principle, applicable in a CRAN setting, they are not efficient for obtaining global CSI as they are not optimized towards multi-connectivity scenarios.

ONE5G has advanced the state-of-art by investigating fundamental system performance aspects, and by developing solutions that are applicable to upcoming 3GPP releases. The results are mainly applicable to Megacity use cases.

Table 3-14 - Summary of key recommendations and benefits for efficient signaling and control for advanced connectivity.

Feature	Recommendation	Link performance/KPI benefits
CRAN Performance under Low-Overhead Channel Estimation	Design of critical parameters for downlink (FDD) CRAN operation such as training overhead and number of cooperating RRHs (cluster size) depend critically on the path loss conditions and should be optimized accordingly. Cooperative transmissions should be considered in propagation conditions with path loss factors close to or greater than 4.	For a propagation path loss factor equal to 3.67, a dense RRH deployment, and a fixed training overhead, cooperative transmissions can provide close to 4 dB SNR gain compared to conventional (non-cooperative) cellular operation. This gain increases for larger path loss factors.
Enhanced CSI Feedback and Downlink Control Channel Transmission	It is recommended to apply the proposed joint WB and SB amplitude quantization methods to achieve accurate CSI feedback based on Type-2 codebook in NR. For reliable reception of downlink control channel scheduling DL/UL data packet, configurable size of resource element group bundle using same precoder is also proposed to achieve good trade-off between diversity and beamforming gain for different channel conditions.	The enhanced CSI feedback accuracy and reliable reception of control channel shall enhance the overall system throughput and spectrum efficiency. Specifically, the proposed optimal CSI feedback can reduce the CSI amplitude quantization error by ~50% compared to the conventional method for Rel-15.
CSI Signalling for NR Network Coordination and	It is recommended to use the proposed signalling procedures in NR network coordination and duplexing, i.e., a non-	Simulations show that 30% performance user downlink throughput gain with the proposed

Duplexing	transparent NCJT mode and cross-link interference management with zero-power CSI-RSs. These are proposed to 3GPP NR standardization in Tdocs.	CLI management procedure.
Optimized Functionality Placement and Resource Allocation in CRAN/DRAN Context	Flexible functionality placement in the Radio Access Network can significantly reduce the cost in terms of latency and energy consumption at the expense of increased computational requirements. The selection of the appropriate centralization level is a challenging task, but even simple methods can offer considerable benefits.	The proposed approach finds the optimal decision regarding functionality placement. We achieve a 30-50% decrease of the considered cost function.

3.4 Proof of Concept and Trials

The work package objectives are as follows:

- Definition of the PoC scenarios and the ONE5G features to be demonstrated in each PoC
- Implementation of a selected set of technologies and optimization techniques as PoC components
- Integration of the components into the PoCs and appropriate PoC configuration
- Assessment of the PoCs in terms of the KPI/KQI targets defined in PoC scenarios

3.4.1 Definition of PoC scenarios

The first objective of the project prototyping activities has been the definition of a set of PoC scenarios covering:

- the main project scenarios, "Megacities" and "Underserved Areas";
- a set of important verticals, mainly running smart city applications, factory applications (Factories of the Future - FoF), automotive applications and agricultural applications;
- the main 5G service categories, eMBB, URLLC and mMTC and;
- a selected set of technologies (TeCs) under investigation within the other WPs for implementation into the PoCs.

A set of five PoCs have been defined and described in detail along with the involved technical components and the ONE5G features to be demonstrated in each of them. In this direction WP5 collaborated with WP3 and WP4 in order to generate the final list of the features and technical components proposed in WP3 and WP4 to be implemented and integrated within WP5. In addition, WP5 collaborated with WP2 in order to further update the PoC scenarios based on the final list of use cases defined in WP2.The final PoC scenarios are summarised below:

PoC#1: Industrial

The aim of this PoC is to test the E2E performance optimization techniques in combination with multi-connectivity techniques. The covered scenario is “megacities” targeting URLLC related services in an industrial area with large factories. Technical components involved: dynamic multi-link/multi-node connectivity (as an enabling technology for supporting high reliability and availability of URLLC services), solutions for optimization of network resources in an end-to-end manner by management of network slices, solutions for URLLC services (e.g. macroscopic transmit diversity, packet duplication at physical layer with single-frequency-network (SFN) type of transmission, coordinated cell muting etc.) and approaches for slice negotiation as the tools to enhance the network decisions in an industrial environment and as an enabler for fulfilling vertical requirements.

PoC#2: “Smart megacity”

The aim of this PoC is to test the E2E performance optimization and multi-node/multi-link techniques, as well as to assess some E2E and context-aware KPIs. The covered scenario is “megacities” serving a large number of users, services and cell densities. The PoC is primarily focused on eMBB and mMTC service categories, but the technologies under investigation are useful for not just a single service category and are intended to enable multi-service coexistence. Technical components involved: multi-link and multiband service aggregation and context-aware multi-service solutions (e.g. RRM optimization), enhancement of traditional load balancing techniques, service-differentiated load balancing and traffic steering management, solutions for URLLC services by utilizing advanced link management based on multi-cell processing and ad-hoc deployment of services on edge cloud.

PoC#3: Enhanced massive MIMO

The aim of this PoC is to assess and demonstrate the potential performance gains of the massive MIMO technology in a multi-user and multi-cell environment. The covered scenario is “megacities” targeting eMBB for the relevant verticals being active in a “smart-megacity” with a large number of users and dense cell deployment. Technical components involved: non-orthogonal multiple access and code design, multiple data path transmission and multi-source synchronization, array design (e.g. MIMO planar antenna arrays and subarrays), sector and beam management and enhanced CSI acquisition techniques for mMIMO.

PoC#4: “Underserved areas”

The main objective of this PoC is to design, develop and implement a low-cost network for use cases in underserved areas. The covered scenario is “underserved areas” targeting primary mMTC and eMBB for agricultural applications, but includes services from the category URLLC as well, though with less stringent requirements than in an industrial setting (like PoC#1). Technical components involved: flexibility and fast reconfiguration of network elements and mechanisms for transmission path improvements, approaches for end-to-end optimization of the low cost 5G network, management of network slices.

PoC#5: Automotive

This PoC aims to expose the potential of 5G ultra reliable low latency communications for V2X services. The covered scenario is “megacities” targeting URLLC for automotive applications, but the scenario “underserved areas” could be considered as well, with less tight URLLC requirements. Technical components involved: flexible short frame structure and frequency bandwidth, flexible pilot pattern, robust synchronization and channel equalization in URLLC, multi-antenna enhancement for improving reliability, as well as optimization of real-time processing in URLLC.
The aforementioned PoC scenarios are reported in detail in [D5.1].

3.4.2 Implementation of PoC components

Initially, an implementation methodology has been defined in terms of identifying a common methodology for the implementation of the selected technical components proposed in WP3 and WP4. In T5.2 two implementation methodologies were defined, one for software and the other for the hardware implementation. According to the software methodology, the technical components will be implemented mainly in C/C++ and alternatively in Java. In cases that Matlab will be used, the appropriate interface with the other components of the testbed should be implemented as well. The hardware methodology will be based on the RF Network on Chip (RFNoC) framework. The actual implementation methodology is reported in [D5.1].
During the project duration, a set of 23 technical components were implemented based on the design consideration from the technical WPs (WP3 and WP4), integrated into the partner testbeds, demonstrated and validated. The TeCs are described in detail in D5.2, while a summary of them is provided in Table 3-15. In this table, for each PoC, the included TeCs are presented, together with the TeC Provider (the partner which proposed the mechanisms and algorithms of the TeC) and the Testbed Owner (the partner which actually implements the TeC and integrated it into its testbed). In addition, the relation of the TeCs described in this document and the TeCs reported in [D5.1] is presented, since in some cases the TeCs described in this document includes more than one elementary TeCs mentioned in [D5.1].

Table 3-15 – Technical components implemented and integrated into the PoCs

PoC	Vertical	TeC #	Technical component title	Relation to TeCs described in D5.1	TeC Provider	Testbed Owner
1	Factory of the Future	1.1	Multi-connectivity for reliability improvement.	• Macroscopic transmit diversity (i.e. multiple base stations transmitting the same signal) • Packet duplication at PDCP level • Packet duplication at physical layer, with single-frequency-network (SFN) type of transmission	AAU	AAU
		1.2	Reliable low latency communication in real industrial scenarios	No direct relation with TeCs defined in D5.1. New TeC defined during the project.	AAU	AAU
		1.3	Compressive sensing channel estimation in CRAN	• Acquisition of downlink channel state information by means of low-overhead non-orthogonal reference sequences, and compressed sensing algorithms at the user	FUB	AAU
		1.4	Cloud control of low latency robot operations	• Optimization of real-time processing in URLLC • Multi-connectivity beamforming for enhanced reliability • Short Packet Structure for Ultra-Reliable Machine-type Communication	HWDU	HWDU
		1.5	Slice negotiation between the vertical side and the operator side.	• Implementation of slice negotiator entities both on Factory owner and Operator sides	WINGS	WINGS
		1.6	Creation of new network slices in order to support the vertical requirements	• Network slice creation supporting the FoF requirements in an area-based and time-based manner • Creation of end-to-end network slices (5G network and cloud resources) • Activation of mMTC network slices for non-critical tasks inside the factory • Activation of URLLC network slices in cases of emergencies	WINGS	WINGS
2	Smart megacity	2.1	FEC (Forward Error Correction)	• Flexibility and fast reconfiguration of network elements according to the requested service requirements	BCOM	BCOM
		2.2	KPI-to-KQI metrics mapping	• QoE-to-KQI and KQI-to-KPI metrics mapping	UMA	UMA
		2.3	Prediction of network performance degradation	• Prediction of network performance degradation	UMA	UMA
		2.4	Enhancement of traditional load balancing techniques	• Enhancement of traditional load balancing techniques	UMA	UMA
		2.5	Service-differentiated load balancing	• Service-differentiated load balancing	UMA	UMA
		2.6	Traffic steering management using	• Traffic steering management using context, user and cell level information	UMA	UMA

			context, user and cell level information			
		2.7	Ad-hoc deployment of services on edge cloud	No direct relation with TeCs defined in D5.1. New TeC defined during the project.	WINGS	WINGS
		2.8	Slice negotiation between the vertical side and the operator side	• Implementation of slice negotiator entities both on vertical side and operator side	WINGS	WINGS
		2.9	Creation of new network slices in order to support the vertical requirements	• Creation of new network slices (including 5G network and cloud resources) in order to support the vertical end-to-end requirements • Management of already established slices in order to continuously fulfil the vertical requirements	WINGS	WINGS
3	Smart megacity	3.1	Machine learning-based adaptive nonlinear receive filtering in non-orthogonal multiple access (NOMA)	• Non-orthogonal multiple access and code design • Multiple data path transmission and multi-source synchronization • MIMO planar antenna arrays and subarrays • Change the configuration of the SDR platform using M-MIMO simulations based on QuaDRiGa channel model and measurement data • Transmission of raw I/Q data in time domain over packet based 10G Ethernet	HHI	HHI
4	Agricultural	4.1	Rx and Tx Digital Front Ends (Rx/Tx DFE)	• Flexibility and fast reconfiguration of network elements according to the requested service requirements	BCOM	BCOM
		4.2	Slice negotiation between the vertical side and the operator side	• Slice negotiation between the vertical and the operator	WINGS	WINGS
		4.3	Network slice creation supporting the vertical requirements in an area-based and time-based manner	• Creation of new network slices (including 5G network and cloud resources) in order to support the vertical end-to-end requirements • Management of already established slices in order to continuously fulfill the vertical requirements • Creation of time-based and area-based network slices	WINGS	WINGS
5	Automotive	5.1	Flexible SDR Architecture Supporting Joint Performance-Complexity Optimization	• Robust synchronization and channel equalization in URLLC • Optimization of real-time processing in URLLC	HWDU	HWDU
		5.2	Short Packet Structure for Ultra-Reliable Machine-type Communication	• Flexible short frame structure and frequency bandwidth • Flexible pilot pattern	HWDU	HWDU
		5.3	Multi-connectivity beamforming for enhanced reliability	• Multi-connectivity beamforming for enhanced reliability	HWDU	HWDU
		5.4	Tele-operated Driving Solution	• Robust synchronization and channel equalization in URLLC • Optimization of real-time processing	HWDU	HWDU

				in URLLC		

3.4.3 Integration of PoC components into the PoC platforms

The final step was the integration into the testbeds. The integration includes the adaptation of the PoCs to the scenario requirements defined in T5.1 (e.g. appropriate configuration of the testbeds), as well as the required implementation actions for the smooth integration of the components into the PoCs. The basis of the PoC integration activities are the 7 testbeds being available in ONE5G (presented in Table 3-16).

Table 3-16 - Testbeds

Testbed	Description and capabilities
Multi-link/multi-node and C-RAN testbed	Total of 48 antenna ports (24 SRD USPRs) which can be grouped or distributed according to the specific application.
MIMO Multi-RAT and multi-band testbed	The testbed includes a MIMO Multi-RAT platform supporting band aggregation (in both license and unlicensed bands).
Flexible reconfigurable testbed	Testbed based on USRP and OAI framework targeting underserved area PoC
Flexible Massive MIMO testbed	The testbeds comprise 2 Massive MIMO cells at 3.5-3.7 GHz with 64 antenna elements.
5G URLLC V2X testbed	The testbed includes a SDR platform with flexible L1/L2 protocol stack. Includes several small form factor UE platform PCs and USRPs.
Full indoor commercial LTE network	The testbed is a full indoor LTE network comprises 12 LTE picocells, each including a WiFi access point and 12 LTE/WiFi-capable cell phones.
Platform for vertical service delivery through 5G technologies	6 USRPs based on OAI, various sensors and actuators and a software platform which support analysis, knowledge building and predictions generation.

The capabilities of each testbed have been identified and a mapping between the five PoCs and the testbeds has been done. In addition, an integration methodology has been defined for the integration of the technical components into the PoC testbeds. We defined two levels of integration: a) integration of technical components into PoCs; b) integration/interworking among different testbeds forming an integrated PoC. Regarding the first item, we defined a methodology based on the Representational State Transfer (REST) protocol for the integration of the software components and a methodology based on the RF Network on Chip (RFNoC) framework for the hardware integration. The actual integration process includes the design and the implementation of the interfaces between the technical component and the testbed. The interface implementation may be required in addition the extension of the testbed with new capabilities (e.g. implementation of functionalities for the measurement of specific parameters required by the component) or new functionalities (e.g. for the realisation of the outcomes of the components). The integration process also includes the appropriate configuration of the software or hardware parts of the testbed and the fine tuning of the component configuration parameters.

Regarding the integration/interworking among different testbeds, this is reported in D5.2, in a per PoC manner. During the first year of the project we focused on integrating components into specific testbeds, while during the second year we focus on integration among testbeds. In this direction, during the second year we defined, implemented and demonstrated Integrated PoCs (IPoCs), meaning PoCs that utilise functionalities prototyped into different testbeds. The following IPoCs were developed and demonstrated (described in detail in [D5.2]).

IPoC#1: Serving megacities and industrial areas through 5G technologies

It is an integrated PoC between AAU, UMA and WINGS testbeds and it was demonstrated in MWC2019. The main goal of the IPoC is to prove the suitability of 5G technologies in supporting the requirements in two challenging environments: a) in industrial areas with large factories; b) in highly populated areas, namely "Megacities". The PoC demo presented the validity and performance of technical components developed in ONE5G and their feasibility through prototyping into megacity and industrial contexts.

IPoC#2: Wireless control of industrial production

It is an integrated PoC between AAU and UMA testbeds and it was demonstrated in EuCNC2019. The PoC demonstrates the usage of prediction techniques to improve communication's reliability in industrial scenarios. It proposes a MLaaS scheme to deploy a mechanism that can predict “a priori” the end-to-end delay and packet loss probability of a mission critical message in a wireless gateway that provides connectivity for an industrial equipment.

Finally, several demonstration activities were conducted. We demonstrated a first version of the “Underserved Areas” PoC in MWC2018 during the "IoT & 5G Use Cases" session. Then ONE5G participated with 5 demonstrators in EuCNC2019 covering all the defined 5 PoC scenarios. In this event we win the "Best Booth Award". During the second year of the project, we demonstrated the first integrated PoC (IPoC#1) in MWC2019, selected (with other two projects) to demonstrate in the 5G IA Booth during the whole duration of the event. Finally, we participated with 5 demons in EuCNC2019 presenting the final version of the PoCs.

In short, the main findings of the prototyping activities are summarized below in the below table.

Table 3-17 - Summary of key finding of the prototyping activities

Related PoC	Related vertical scenario	Key finding
Industrial	Factories of the Future (FoF)	In industrial scenarios, the adoption of multi-connectivity solutions in improving the reliability of the communication link has been assessed. Different multi-connectivity solutions have been demonstrated; physical layer solutions such as SFN and non-coherent JT, as well as higher layer duplication. Results prove the capability of multi-connectivity solutions in improving the receive SINR especially in low scenarios characterized by high LOS probability. Physical layer multi-connectivity solutions outperform high layer duplication, at the expense of a higher cost. The penalty of multi-connectivity in terms of maximum throughput in the considered network has also been estimated.
Smart Megacity	Smart city	In Megacity scenarios, multiple novel approaches for cellular management, with focus on QoE and E2E monitoring/modelling as well as context-awareness and slice negotiation procedures were prototyped and validated. KQIs can be properly estimated as well as forecasted based on low-layer metrics. Also, load balancing algorithms supported by QoE estimation or direct measurement allow to highly improve the performance in the network. Moreover, adding context information relative to the position of the users increases these benefits, validating it as a solid option for the development of new standards of cellular network management.
Smart Megacity	Smart city	In Megacity scenarios, mechanisms for the ad-hoc deployment of services on edge cloud demonstrates and validated the latency improvements as well as the minimization of the throughput between the BS and the Cloud.
Enhanced massive MIMO	Smart city	In Megacity scenarios, machine learning can replace some building blocks of wireless NOMA receivers in the regime of having more UEs than receive antennas at the BS. A practical nonlinear machine learning based technique that works with short training and a small number of antennas were demonstrated and validated, outperforming linear methods with fewer antennas.
Underserved Areas	Agricultural	Underserved Areas solutions for the flexible and fast reconfigurable hardware can be used in order to lower the network deployment and operation cost.
Underserved Areas	Agricultural	The adoption of slice negotiation and management solutions helps in fulfilling the network requirements of the verticals in a cost-effective way by requesting network slices in an ad-hoc manner.
Automotive	Automotive	In automotive scenarios, the following solutions improves the latency in URLLC services: low-latency frame structure,

		reliability enhancement with multi-connectivity beam-forming and flexible SDR architecture. The improvements were demonstrated using a complete tele-operated driving system.

3.5 Exploitation, dissemination, standardization, innovation

3.5.1 Exploitation

ONE5G partners have been highly active and published more than 141 publications in all relevant major ICT conferences including ICC, Globecom, VTC, ISWCS, EW, PIMRC, WCNC etc. Industry and SME partners have greatly exploited their results by contributing to 3GPP standardization with 52 contributions so far, as described in the following section and in the Annex.

Exploitation in industry

The industrial partners have used the project work for internal collaboration with the respective teams being active in standardization, marketing and product development. In an early stage, the concepts, system design and evaluation results are one valuable source of information for the strategy building within the companies. This includes the building of initial product and feature roadmaps and decisions on areas to invest in research and development.
The SMEs as well as the large industry partners have handed over results out of the project work into their development processes to come up with new product variants and to improve their existing solutions thus helping to build up relevant know-how. Large industry is now considering the enhancements of 5G and additions in their product roadmap. The quantitative evaluation and the techno-economic studies help setting up reliable product roadmaps, and the work undergone in ONE5G was key in helping us to acquire know-how about the potential and trade-offs of the 5G enhancements.
Research as it has been carried out in ONE5G investigates the entire system. Besides the standard-relevant aspects the work also results in designs, architectures, functions and algorithms that provide a necessary basis for the analysis, engineering and implementation of the systems – and this is not described in any standard. This part of the project's results is being disseminated within the partner's organization to the technical (development) community and it becomes one basis for the development work.

The prototypes give some evidence on the feasibility of a network solution, even if the prototype is limited. Providing often a physically realistic implementation of a (sub)system the realization of a proof of concept often leads to the discovery of issues and solutions that have not been thought of in design and simulation. In this sense the prototypes have helped to de-risk the development.
The main benefit of a proof of concept however is that it can illustrate potential new use cases. This aspect is important in the case of ONE5G that works to expand the use cases to the evolved 5G addressing vertical sectors and industrial applications. These markets are still in their infancy and the community still is learning how to use communication technology in these sectors. The visibility of solutions provided in the demos thus accelerates the adoption process of communication technologies in the industrial sector and helps to evolve these markets.
The techno-economic studies are also of particular value for the operators, since they allow to plan and realize viable deployments, especially in Underserved areas.
The fact that ONE5G partners were (and continue to be) able to contribute into the 3GPP gives us higher credibility within the ecosystem. This is quite important for the large companies and especially for an SME.

Exploitation by academia

As part of their activity, the universities and companies have trained numerous Bachelor, Master and PhD students. Additionally, existing lectures have been improved and dedicated lessons have been developed based upon the work in ONE5G. Technologies have been incorporated as examples and state of the art developments to enhance student awareness and to offer cutting edge knowledge.
Eventually, national and international industrial research projects will be fostered through the acquired know-how and supported by the built network of contacts within the 5G field.

Partners of ONE5G have been able to use the work in the project to strengthen their expertise and their standing within the global technical community. Altogether, ONE5G research results have strengthened the position of European companies in the standardization and overall ICT domain.

3.5.2 Dissemination activities

ONE5G dissemination has been based on manifold pillars: activities aim at intra and inter project concertation, workshops, special sessions, training activities, industry booths. Particularly, ONE5G has fostered (joint) scientific publications and joint publications in the major IEEE and European conferences as well all relevant leading IEEE journals. Altogether, throughout its lifetime, ONE5G has delivered:

- 4 major international workshops, e.g. GLOBECOM 2018
- 3 special sessions including IEEE 5G tutorial
- 5 industry booth participations at major expositions, e.g. the MWC 2018/19 exclusively selected by the 5G-IA
- 141 Publications in the flagship ICT/IEEE conferences/journals

As part of these activities ONE5G has received special recognition through:

- Best Booth Award at the EuCNC 2018
- EuCNC 2018 Best Paper Award

ONE5G has complemented this with strong presence in social media and promoted events and results produced by the project through the website https://one5g.eu/ and from the outset of the project. Altogether, throughout its lifetime, One5G has reached:

- 435 Followers (by July 2019)
- 501 LinkedIn group members (by July 2019)
- all relevant stakeholders groups through 13 major public events

Eventually, ONE5G actively participated in related 5GPPP and the 5G IA coordination and steering activities for major events (such as the MWC), working groups, as well as on-going consultations for upcoming 5GPPP phases and related H2020 program initiatives. In addition, ONE5G made use of 5GPPP-specific dissemination channels (EURO-5G news/events update, 5GPPP webpage, 5GPPP white papers/brochures, "European 5G Annual Journal").

The overall dissemination activities within the project are detailed in the sections below.

Inter-project Concertation

ONE5G has actively participated in the inter-project concertation (e.g. joint workshops, industry panels and special sessions) as part of the 5GPPP To-Euro-5G coordination action, the 5GPPP working groups/steering boards, and the 5G-IA. Whenever it was possible, ONE5G has proposed joint workshops, special sessions, tutorials, invited talks or other joint events, e.g., in international conferences, project meetings or similar forums. ONE5G has contributed to relevant white papers or other publications initiated by the 5GPPP steering board/working groups throughout 2018/2019. Specifically, ONE5G actively contributed to *The European 5G Annual Journal 2018* https://5g-ppp.eu/annual-journal/ and 2019 (https://5g-ppp.eu/the-2019-edition-of-the-european-5g-annual-journal-is-out/).
ONE5G has closely collaborated with 5GPPP To-Euro-5G coordination action (particularly with Jacques Magen, Jose Gonzalez, Giulia Pastor, Carole Manero) as well as the related communication channels, i.e. EURO-5G EVENTS UPDATE comms@5g-ppp.eu, EURO-5G NEWS channel and EURO-5G Twitter account(s). ONE5G has well

collaborated with other 5GPPP Phase2 (or related, e.g. 5G-CHAMPION) projects through joint workshops, special sessions (5G-XCAST, 5G-MONARCH) or advisory board activities (5G-CAR). The following table summarizes the joint activities.

Table 3-18 - Inter-project activities

Activity	Series	Time	Venue	Topic	5GPPP Partner
Joint Workshops	WCNC 2018	April 15, 2018	Barcelona, Spain	5g enabling technologies 5g Broadcast and Multicast 5g URLLC advances 5g Standardization	ONE5G 5G-XCAST
	CLEEN 2018	June 3, 2018	Porto, Portugal	Cloud Technologies and Energy Efficiency in Mobile Communication Networks	5G-CHAMPION
	GLOBECOM 2018	December 9 -13, 2018	Abu Dhabi, UAE	5G Advanced: The Next Evolution Step of 5G NR	ONE5G 5G-XCAST
	WCNC 2019	April 15-19, 2019	Valencia, Spain	Advanced 5G radio access network features and performance	ONE5G 5G-XCAST
Booths, Video Demo	MWC 2018	April 15, 2018	Barcelona, Spain	5G and use cases 5G and consumers	ONE5G (WINGS), 5GCAR etc.
	5G FORUM	April 24-25, 2018	Malaga, Spain	Revolucionando la industria y la esperiencia de usuario	
	EuCNC 2018	June 18-21, 2018	Ljubljana, Slovenia	5G Mobile Network Architecture and New Radio Advances (5GMoNANeRA)	ONE5G 5G-MONARCH
	MWC 2019	February 25-29, 2019	Barcelona, Spain	5G Technical Demo	5G-Media One5G 5G-MoNArch

Scientific Publications

The project partners have disseminated their innovation results in high quality scientific journals and all the major 2018 and 2019 conferences such as IEEE ICC, IEEE GLOBECOM, IEEE VTC and many others. The extensive list is referenced in the respective sections in this report. Joint IEEE magazine papers or IEEE Access paper have been meanwhile accepted, such as:

- *Exploiting the Massive MIMO Channel Structural Properties for Minimization of Estimation Error and Training Overhead* by S. Bazzi (Huawei Technologies Duesseldorf GmbH), S. Stefanatos (Freie Universität Berlin), L. Le Magoarou (b<>com), S. E. Hajri (CentraleSupelec) ,M. Assad (CentraleSupelec), S. Paquelet (b<>com), G. Wunder (Freie Universität Berlin), and W. Xu (Huawei Technologies Duesseldorf GmbH)..

Eventually, ONE5G partners have received also the *best paper award* in EuCNC 2018 for the paper:

- *PMEC – assisted End-to-End Latency Evaluations for C-V2X Communications* by M. Emara (Hamburg University of Technology, Germany), M. Filippou (Intel Germany GmbH, Germany), D. Sabella (Intel, Germany).

Workshops, Special Sessions, Panels, and Tutorials

The consortium has targeted flagship 2018 and 2019 conferences such as IEEE WCNC 2018/19, IEEE VTC 2018, EuCNC 2018/19, and IEEE GLOBECOM 2018 for organizing industry panels, special sessions, workshops or tutorials on 5G individually and together with the other 5GPPP Phase2 projects (see cross-collaboration). The following table summarizes the project individual activities.

Table 3-19 - Workshops, Special Sessions, and Tutorials

Activity	Series	Planned Date	Venue	Topic
Major workshop series	WCNC 2018	April 15, 2018	Barcelona, Spain	5g enabling technologies 5g Broadcast and Multicast 5g URLLC advances 5g Standardization
	CLEEN 2018	June 3, 2018	Porto, Portugal	https://5g-ppp.eu/cleen2018/
	GLOBECOM 2018	December 9 -13, 2018	Abu Dhabi, UAE	5G Advanced: The Next Evolution Step of 5G NR
	WCNC 2019	April 15, 2019	Marrakech, Morocco	Advanced 5G radio access network features and performance
Special Sessions	EuCNC 2018	June 18-21, 2018	Ljubljana, Slovenia	5G Mobile Network Architecture and New Radio Advances (5GMoNANeRA)
	EuCNC 2019	June 18-21,	Valencia, Spain	5GPPP ONE5G project: Moving

		2019		5G towards 5G Advanced
Industry panel	WCNC 2018	April 17, 2018	Barcelona, Spain	New Perspectives on Wireless Communications and Networking for Industrial Automation
Tutorials	IEEE 5G Tutorial	November 12, 2018	Aalborg, Denmark	5g enabling technologies ONE5G

Booth and Demonstrations at Industry Expositions

All partners in the consortium have periodically participated in different conferences, public events, industry trade shows and other marketing and public relation actions. Among these events, the consortium has specifically targeted the EuCNC 2018/19, MWC2018/19, and other special events (such 5G FORUM exposition) in order to demonstrate the technological achievements of the project. ONE5G was awarded with the best booth prize in EUCNC 2018. The following table summarizes the major activities related to booths and demos.

Table 3-20 - Booths and Demos

Event	Date	Venue	Topic	Lead partner
MWC 2018	February 26, 2018	Barcelona, Spain	5G and use cases 5G and consumers	WINGS
5G FORUM	April 25 - 26, 2018	Málaga, Spain	https://www.5gforum.es/	University Malaga
EuCNC 2018	June 18-21, 2018	Ljubljana, Slovenia	5 PoCs presenting the indermediate state of WP5	WP5 partners
MWC 2019	February 25-28, 2019	Barcelona, Spain	Multi-layer 5G multi-connectivity for reliability enhancement, end-to-end monitoring schemes, and slice negotiation for industrial and megacities environment.	Aalborg University, University of Malaga, and WINGS
EUCNC 2019	June 18-21, 2019		5 PoCs shown, presenting the final version of WP5 https://www.eucnc.eu/exhibitions-and-demos/	WP5 partners

Figure 3-2: ONE5G team at the EUCNC2019 booth

Public Website, Flyers, and Videos

ONE5G hosts a comprehensive public website updated timely to cover all relevant activities. The website is available at https://one5g.eu/ . The website contains all relevant information about the project, such as the project vision and objectives, the relation of the project to the funding programme and other projects in the same domain and the consortium details. The site has been updated over the lifetime of the project with the public deliverables, publications, and public materials, such as flyers ('factsheets') and posters. It has provided an overview of all the project's events including:

- dedicated GLOBECOM 2018, WCNC 2018/2019 workshop webpages
- videos of major booth activities e.g. the video of MWC 2019 demo booth [MWC2019_video]: https://one5g.eu/wp-content/uploads/2019/03/one5g-@-mwc19_compressed.mp4

The website has been constantly (in real-time) updated particularly due to the embedded Twitter messages (Twitter updated online from panels etc. possible) as shown in the figure below.

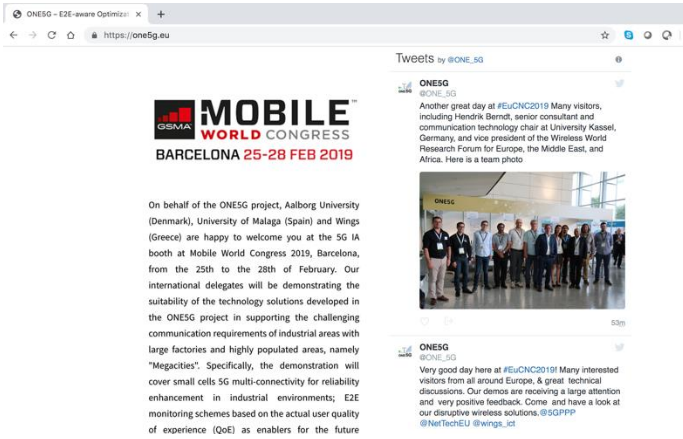

Figure 3-3: ONE5G at Mobile World Congress 2019

Social Media Representation, Video streaming

Different social networking groups (e.g., Twitter, LinkedIn) have complemented ONE5G's website. Through social networks, the project has advertised its results, has announced events, has informed about the most recent results and reports, and has provided a platform for discussion. For the main events (e.g. MWC 2019, EuCNC 2019, EuCNC 2018) ONE5G has used *Twitter live steaming* to broadcast events to the general public. Specifically, ONE5G has set up the following social media channels:

Twitter account: The Twitter account is constantly used for online messaging, and posting of news (like NGMN participation etc.). ONE5G has >400 followers and is following >80 accounts. The account is also a good mean for the cross-project interaction (Re-Tweets by 5GPPP To-Euro-5G related Twitter accounts), as shown in the figure below ONE5G retweet on WINGS ICT Solutions tweet.

Figure 3-4: ONE5G au EUCNC 2018

ONE5G has reached 18.2K impressions through its Twitter channel and promoted own and partner events, resulting in 203 impressions per day on average. This is mostly due to the impact of the live stream from GLOBECOM'19 workshop and the demo in MWC'19. Excluding these two major events, ONE5G twitter channel had on average 60 impressions per day, for instance, in January 2019, which indicates a considerable increase in the unstimulated attraction of audience as shown in the figure below.

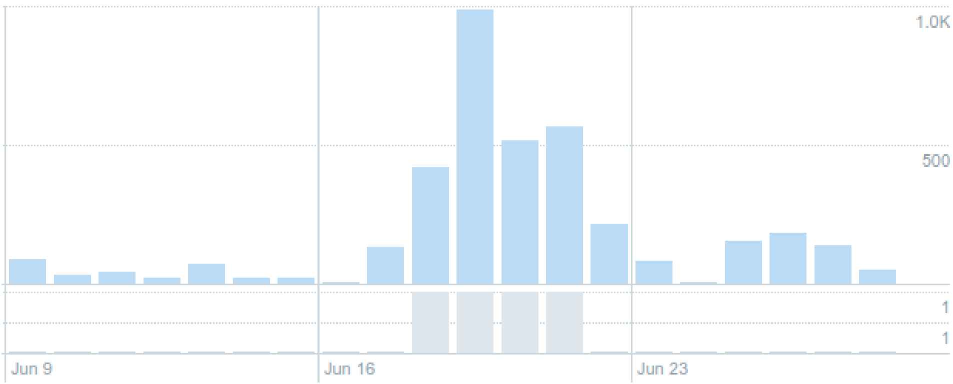

Figure 3-5: Number of Twitter impressions per day

LinkedIn group: The ONE5G LinkedIn group has been used to spread technical and workshop/panel announcements and technical content among stakeholders, academia, industry etc. The group has already >500 members constantly collaborating in the platform as noticed in the figure below.

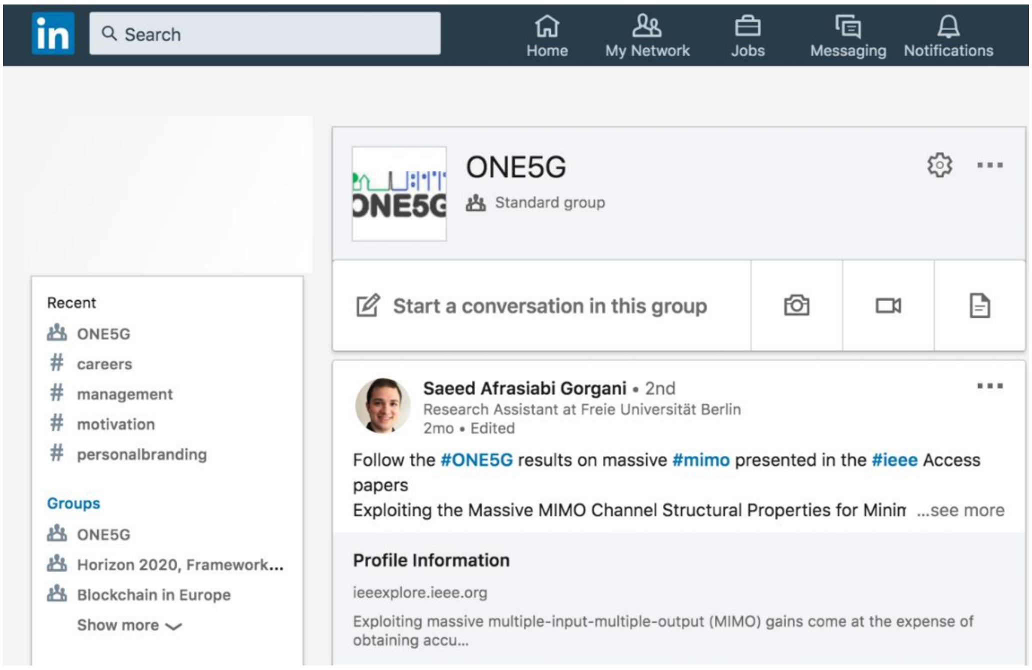

Figure 3-6: ONE5G Linked In group

3.5.3 Standardization

ONE5G's impact on 3GPP NR standardization is summarized in the following. Table 3-21 and Table 3-22 summarize impact on the NR Release-15 specifications. In this context, it should be noted that the 3GPP entered the work item phase for completion of Release-15 at the start of ONE5G. Secondly, Table 3-23

Table 3-22 Summary of impact on 3GPP NR Release-15 specifications (WP4)

Feature	Description	3GPP reference
Cross-link interference mitigation	Interference management solutions enabling IAB in NR, NR duplexing with CRAN and network coordination. Also, CSI framework for network coordination.	During Rel-15 NR WI, enablers for basic support of cross-link interference mitigation schemes to support duplexing flexibility for paired and unpaired spectrum were discussed, but the work has been deprioritized. Follow-up activity: REL-16 WID NR_CLI_RIM "Cross Link Interference (CLI) handling and Remote Interference Management (RIM)", see RP-190700
PDCCH structure	Configurability of REG bundle size for PDCCH operating in different interference scenarios.	RP-172115 Work Item on New Radio (NR) Access Technology scheduling/HARQ aspects, PDCCH structure TS 38.211, 38.212, 38.213, 38.214.
Massive MIMO Uniform Circular Arrays	Circular antenna arrays for more flexible adaptation to varying user distributions.	General contribution to MIMO channel modeling, TR38.901 and follow-up specifications.
PT-RS for CoMP and MU-MIMO	PT-RS power boosting	NR MIMO (Reference signals and QCL) TS 38.211, "NR; Physical channels and modulation," 2018. TS 38.214, "NR; Physical layer procedures for data," 2018.

- Release 16

Table 3-23 Summary of impact on 3GPP NR Release-16 Study and Work Items (WP3)

and Table 3-24 summarize ONE5G's impact on various 3GPP NR Release-16 Study and Work Items. NR Release-16 is set to be finalized by end of 2019. Finally, several of the developed innovations in this project are candidates to be included in future 3GPP NR releases such as 17 and 18, those are summarized in Table 3-25 - Candidate features for future 3GPP NR Releases such as 17 and 18 (WP3).Table 3-25 and Table 3-26.

- Release 15

Table 3-21 Summary of impact on 3GPP NR Release-15 specifications (WP3)

Feature	Description	3GPP reference
Preemptive scheduling	Mux of eMBB and URLLC with different TTI sizes, interrupted transmission indication and CBG-based HARQ retransmissions.	3GPP TS 38.300 Section 10.2, 3GPP TS 38.214 Sections 9.1 and 11.2.
RRC state machine	Definition of the new RRC INACTIVE state and related state transition rules.	3GPP TS 38.300 Section 7, 3GPP TS 38.304, and 3GPP TS 38.331
FR1 & FR2 Carrier Aggregation	Radio resource allocation for services mapping, needs the possibility of aggregating NR FR1 (N77) & NR FR2 (N258) simultaneously	3GPP TS 38.101 Section 5.2 and TS 138.133 Section 8.1.7
UE-specific BWP inactivity timer configuration	UE-specific BWP inactivity timer can be configured for each serving cell so as to optimize the UE operation time duration in the configured non-default BWPs to enable power saving.	3GPP TS 38.321 Section 5.15 and TS 38.331 Section 6.3.2

Table 3-22 Summary of impact on 3GPP NR Release-15 specifications (WP4)

Feature	Description	3GPP reference
Cross-link interference mitigation	Interference management solutions enabling IAB in NR, NR duplexing with CRAN and network coordination. Also, CSI framework for network coordination.	During Rel-15 NR WI, enablers for basic support of cross-link interference mitigation schemes to support duplexing flexibility for paired and unpaired spectrum were discussed, but the work has been deprioritized. Follow-up activity: REL-16 WID NR_CLI_RIM "Cross Link Interference (CLI) handling and Remote Interference Management (RIM)", see RP-190700
PDCCH structure	Configurability of REG bundle size for PDCCH operating in different interference scenarios.	RP-172115 Work Item on New Radio (NR) Access Technology scheduling/HARQ aspects, PDCCH structure TS 38.211, 38.212, 38.213, 38.214.
Massive MIMO Uniform Circular Arrays	Circular antenna arrays for more flexible adaptation to varying user distributions.	General contribution to MIMO channel modeling, TR38.901 and follow-up specifications.
PT-RS for CoMP and MU-MIMO	PT-RS power boosting	NR MIMO (Reference signals and QCL) TS 38.211, "NR; Physical

		channels and modulation," 2018. TS 38.214, "NR; Physical layer procedures for data," 2018.

- Release 16

Table 3-23 Summary of impact on 3GPP NR Release-16 Study and Work Items (WP3)

Feature	Description	3GPP reference
UE power consumption model and WUS-triggered DRX	State-of-the-art UE power consumption model, capturing effects of different RRC states and DRX, and WUS-triggered DRX study.	3GPP SI on UE power consumption (RP-181463) and 3GPP TR 38.840.
Enhanced DC/CA with PDCP duplication	Resource efficient DC/CA with PDCP data duplication for URLLC services and its extension to up to 4 duplicates.	3GPP SI on IIoT (RP-181479) and 3GPP TR 38.825, and 3GPP WI on IIoT (RP-190728).
Enhanced mux of eMBB and URLLC	Inter-UE mux of eMBB and URLLC and URLLC system-level performance assessment	3GPP SI eURLLC (RP-181477) and 3GPP TR 38.824.
DPS and Centralized URLLC scheduling	Evaluation of multi-TRP DPS and centralized multi-cell scheduling of URLLC.	MIMO (multi-TRP aspects) (RP-182075)
FR1 (NR) & FR2 (NR) Carrier Aggregation	Radio resource allocation for services mapping, needs the possibility of aggregating FR1 (N77) & FR2 (N258) simultaneously	3GPP WI on DC and CA enhancements (RP 181469)
In-band signaling enhanced DRS mechanism for the operation in unlicensed bands	Proposed DRS signaling modifications in dense coexistence scenario for improved eMBB service performance measured in KQI	3GPP New WID on NR-based Access to Unlicensed Spectrum (RP-182806)
QoE-KQI-KPI mapping	This functionality gives response to the difficulty of network operators to gather high-layer end-to-end performance metrics (KQIs and QoE) by estimating them from lower layers metrics using machine learning techniques. These high-layer performance metrics will afterwards be used by other network management mechanisms.	3GPP Study of enablers for Network Automation for 5G (TR 23.791).

Table 3-24 Summary of impact on 3GPP NR Release-16 Study and Work Items (WP4)

Feature	Description	3GPP reference
2-step RACH for NR	NOMA for random access (follow-up activity after NOMA study item has been finished in Dec 2018)	Work item: 2-step RACH for NR NR_2step_RACH (RP-190711) RACH procedure (TS38.213

		and TS38.321)
CLI management for IAB	Interference management solutions enabling IAB in NR	FS_NR_IAB "Study on Integrated Access and Backhaul for NR" in RP_181349. TR 38.874 Study on Integrated Access and Backhaul for NR
CSI for MU-MIMO	CSI Enhancement for MU-MIMO Support	NR_eMIMO "Enhancements on MIMO for NR" RP-181453 (June 2018)
NOMA	Comparison of 5G NOMA schemes	FS_NR_NOMA "Study on non-orthogonal multiple access for NR" (RP-181403) TR-38.812

- <u>Release 17 and 18</u>

For future 3GPP NR Releases (i.e. Rel-17 and Rel-18), the following table summarizes the developed enhancements that ONE5G consider as promising for upcoming standardization activities.

Table 3-25 - Candidate features for future 3GPP NR Releases such as 17 and 18 (WP3).

Feature	Description	3GPP impact
MU-MIMO null-space preemptive scheduling	Promising method that exploits the spatial dimension to more efficiently multiplexing eMBB and URLLC users for cases with at least 8 gNB antennas.	Requires additional NR standardization of gNB-2-UE signaling to facilitate good isolation between co-scheduled eMBB and URLLC users (i.e. new DCI formats)
Enhanced C-RAN multi-cell scheduling	Centralized multi-cell scheduling offers significant benefits. Developed methods can to a large extended be implemented for NR Release 15 and 16 specs, but additional 3GPP specs would still be useful.	Enhanced signaling options for the F1 (higher layer split option) and F2 (lower layer split option) interfaces, should 3GPP chose to standardize F2.
a D2D relaying scheme for mMTC	A D2D relaying scheme adapted to the specific mMTC constraints in terms of energy consumption and based on a discovery protocol inspired by the 802.11 RTS/CTS protocol. Promising performances in terms of optimization of the MTC device energy consumption have been shown.	A new discovery procedure to be included in D2D work item for NR mMTC rel. 17/18
Component carrier management in multi-connectivity	This functional block aims at dynamically assign PSCells and SCells to UEs, by hosting these in the CCs that best	- New mechanism for cell addition/removal/change (beyond current mobility triggering events).

environment	fit according to network operators' policies. This will bring benefits both in terms of enhanced throughput and in reliability, depending on whether the data flow among the selected CCs is split or duplicated, respectively.	- Development of mechanisms to gather/process network performance information beyond traditional radio KPIs (e.g., context, KQIs, etc.). Initially addressed in Rel-16 TR 23.791 with NWDAF.
Uneven traffic split among component carriers in multi-connectivity environment	This functionality aims at complementing the dynamic assignment of component carriers and provides a way to fine-tune the usage of radio resources among currently assigned component carriers, according to the network state by appropriately assigning the amount of traffic to be held by each of them.	- Currently applicable to 5G dual-connectivity scenarios. - However, for its benefits to be maximized, it should be operated jointly with the dynamic component carrier management in a 5G multi-connectivity scenario.
QoE steering	Following a mobility-based approach, this mechanism uses UE and network performance information to estimate each UE's perceived QoE, which is afterwards used to hand UEs over cells in order to steer/balance this QoE.	- Inclusion/development of methods for per-service QoE estimation using lower-layers performance information. - Inclusion of per-service handover margins.
Proactive context-aware network management	This functionality aims at analysing and forecasting network performance, identifying the cause of past degradations and proactively identifying future ones before they actually have taken place, particularly for those generated by causes outside of the network elements themselves (e.g. event-caused crowds). In this way, corrective actions can be defined and applied in advance (e.g. preventive allocation of resources). This will allow preventing UEs from experiencing such degradations and an optimized allocation of resources.	- Development of mechanisms to gather/process context information from a variety of sources (e.g., social networks). Initially addressed in Rel-16 TR 23.791 with NWDAF.
Dynamic resource allocation for service mapping	Objective is to specify radio resource management algorithms that take into account the service policies by allocating dynamically the service to the macro gNodeB and/or µυgNodeB	New mechanism to select/aggregate/connect the cells to optimize users' resource allocation in dense network
Small Data Transmission in RRC INACTIVE state	Design of small data transmission (SDT) during RRC INACTIVE state, without state transition to RRC CONNECTED.	Requires additional NR standardization of e.g. RRC and MAC related to the UE procedures in RRC INACTIVE.
RRC state handling for URRL V2X	Objective is to assess the benefits of using the idle and inactive states for V2X applications, taking into account the stringent delay requirements.	Framework for state selection between idle and inactive in V2X applications.
Dynamic resource allocation for URLLC	Design of a resource allocation policy with absence of CSI knowledge at the	Adapted for cases where the BS cannot know the CSI of the

services	transmitter	URLLC users due to the short latency. In future releases, with the increase of number of URLLC users with more stringent latency requirements, the proposed method will be interesting.
Stochastic resource optimization for heterogeneous architecture	We developed fully distributed scheduling for D2D that achieves a trade-off between throughput and power consumption.	This requires new signaling and frame structure since the proposed policy requires the implementation of a contention procedure.
Power consumption reduction for mMTC	Development of a promising framework that has led to a simple transmission strategy for mMTC (on-off) that reduces their power consumption	The method requires a new signaling in both uplink and downlink
D2D relaying for eMBB	Development of a new distributed relay selection policy in the context of limited feedback.	The framework requires new signaling to send the CSIs and the relay selection in D2D.
Configured grant assignment for misaligned periodic traffic	Proposed scheme to continually adjust BS' estimate of traffic periodicity and time of arrival of next packet.	The scheme requires that the BS keeps and updates simple state variables when observing new arrivals.

Table 3-26 - Candidate features for future 3GPP NR Releases such as 17 and 18 (WP4).

Feature	Description	3GPP Impact
Grant-free URLLC	Solution for UL inter-UE multiplexing between eMBB and URLLC	NR_eURLLC_L1 "SID on Physical Layer Enhancements for NR URLLC" (RP-181477)
NOMA	ONE5G has developed enhanced NOMA techniques for increasing the number of supported devices per cell, which is particularly important for mMTC. Our approach includes regular spreading matrices, spatial preamble reuse, and reinforcement learning for preamble selection. Also, we propose NOMA for service coexistence, particularily for sharing resources between different service types, e.g. eMBB and URLLC.	The Rel-16 study item has not led to a dedicated NOMA work item. Instead, it is expected that different aspects of NOMA will be continued in more specialized 3GPP studies, e.g. on random access, or URLLC/eMBB multiplexing, in Rel-17 and beyond.
High-quality CSI for massive MIMO and CRAN	ONE5G developed techniques for improving the CSI feedback quality for massive MIMO, either by improving the CSI feedback quality of NR procedures (Type-II codebook) or reducing the feedback overhead without cost in CSI quality. Regarding quality of the acquired CSI itself by means of training, advanced	The improved Type-II quantization scheme can be applied directly to current NR. Together with our results for optimized training and feedback overhead, this is to be considered in future 3GPP releases (Rel-17 and beyond).

	estimation algorithms requiring low training overhead were proposed exploiting structural properties of the wireless channel (e.g., sparsity). Also, novel signalling schemes were developed, building on procedures currently available in NR. These schemes allow for improved CSI quality in multi-connectivity (CRAN) scenarios with heavy cross-link interference such as dynamic TDD.	The proposed NR signalling procedure for multi-connectivity CSI acquisition is already considered as a candidate solution in 3GPP.
Low-complexity CSI acquisition and robust beamforming	ONE5G has developed efficient solutions that mitigate pilot contamination by utilizing power control and channel-correlation between multiple-users in both first and second-order statistics. Also, spatial multiplexing techniques for pilot reuse have been developed for TDD and FDD.	The results suggest a flexible RS framework to be considered in future 3GPP releases (17 and beyond), with a training overhead that may change depending on the operational conditions and/or SNR performance requirements.
Pilot Contamination Mitigation	WP4 has developed efficient solutions that mitigate pilot contamination by utilizing power control and channel-correlation between multiple-users in both first and second-order statistics. Also, spatial multiplexing techniques for pilot reuse have been developed for TDD and FDD.	While power control is already supported in 5G, the utilization of correlated multiple user channels requires further signalling between users and users-to-network. This is to be considered in future 3GPP releases (Rel-17 and beyond).
Massive MIMO Beamforming for Backhaul and Multicast	ONE5G proposes new algorithms to shape backhaul signals and to coordinate interference between access and backhaul. On top, further SNR gain is achieved by Probabilistic Amplitude Shaping. This is complemented by beamforming designs for point-to-multipoint multicast channels.	Beamforming is expected to play a crucial role in 5G, in particular for high frequencies and [TR38.913] 3GPP TR 38.913 "Study on scenarios and requirements for next generation access technologies " . Our results relate to [TR38.874] and follow-up activities in 3GPP. Furthermore, multicast beamforming might become relevant for a possible future study item "NR mixed mode broadcast/multicast" (see [RP-180669], which was postponed.
Flexible functional split in CRAN	Motivated by the flexibility offered in a CRAN scenario, an efficient algorithm allowing for optimal distribution of functions among centralized (BBU) and	The solution exploits the flexibility offered by the multiple functional splits planned to be supported by

	distributed units (RRHs) was developed. The algorithm adjusts to the current traffic type and user requirements and aims at achieving multiple objectives such as improved user experience and reduced power consumption.	3GPP [TR38.801]. Application in specific scenarios may suggest/promote a subset of the functional split options currently considered by 3GPP.
Cell-free operation	For massive-MIMO enabled cell-less systems, novel scheduling schemes based on user grouping were developed that result in a reduction of pilot contamination effects with low-complexity receiver processing (matched filtering). Algorithms for joint power control and UE-to-RRHs association were also developed. For the case of an overloaded system (more users than antennas), non-linear detectors are employed, which adapt to the non-stationarities of the environment via a machine learning approach, outperforming conventional (linear) detectors.	The WP4 solutions offer significant gains compared to conventional (non cooperative) massive MIMO. They suggest new signalling in order to implement the user grouping, pilot allocation, and adaptation of non-linear detectors, to be considered in future 3GPP releases (17 and beyond).
Extreme reliability enabled by multi-link connectivity	New vertical industry applications, such as robotised automatic processes (Factory of the Future) and V2X, will impose extreme requirements on reliability (up to $1\text{-}10^{-9}$). ONE5G has developed solutions for exploiting the diversity offered by multi-link communication, with potentially multiple RRHs associated with any UE.	Multi-link connectivity is seen as an enabler for advanced services that require new degrees of reliability and spectral efficiency. In a broad sense, this is related to the current 3GPP discussion on “Multi Connectivity” [TS37.340]. See also_eURLLC_L1 "SID on Physical Layer Enhancements for NR URLLC" [RP-181477]

The list of all the contributions related to ONE5G is available in the Annex. It should be noted that this list will continue expanding beyond the end date of the project, as the partners will continue submitting contributions based on the work achieved during the project’s lifetime.

3.5.4 Innovation

During the lifetime of ONE5G several innovation achievements were recognized including IPRs, standards, new products and services. As part of the Innovation Management, we moved from initial concept development and prototypes, towards testing in the production environment and inclusion of the final solutions to standards.

This ensured that the results are cost-effective, practical, and tailored to the market needs. As such, for the exploitation of innovation in big companies it is essential to maximize the synergy between corporate business development and R&D. An approach for achieving it was the stimulation of collaboration with R&D departments of big companies with business development ones. Also, for SMEs and academia it is essential to align the development and prototypes of R&D with emerging business opportunities.

Due to the composition of the ONE5G consortium main emphasis was given on the production of IPRs and standards. The project was committed to have a strong presence in major standardization bodies like 3GPP through the main industrial partners in order to increase the impact of project's findings and open the way to the market. Details are also mentioned in Standardization subsection of the document. Also, the following IPRs have been filed so far:

- Selective MCS Exclusion for URLLC users to reduce queueing delay.
- Control and Data Channel for NOMA Grant-Free.
- Techniques for digital Beamforming and MIMO Detection.
- Base Station, Use Equipment and Methods for Sending and Receiving a Multicast Beam in a telecommunications network
- A method for mitigating inter-numerology interference
- Encoder, Decoder and Methods for Encoding and Decoding
- A Coordinated Beamforming Method with Inter-cell Channel Covariance Information Exchange

Further innovations were also introduced by SMEs which are not necessarily patented but are related to the creation of new or enhanced products and services. For instance, WINGS -as an SME- proceeded to the development and exploitation of a 5G system-level simulator for performance evaluation of project's technical components. System level simulations in the 5G era, have demanding use cases with high load and very limited latency in order to cover services such as eMBB, mMTC and URLLC. As such, appropriate configuration, environment and network models are implemented in order to proceed to performance evaluation and verticals and operators can benefit from such evaluations before service deployments. Apart from the "system-level simulation platform for performance evaluation of 5G services", other innovations that have been identified and elaborated by partners are:

- Physical Layer Improvement with FEC (Forward Error Correction) Encoder/Decoder for link adaptive coding
- Slice negotiation functionality
- Low-complexity array designs
- Grant free access for mMTC/low latency access (NOMA enabled receiver)
- Resource allocation and management for NOMA

- QoE framework and resource allocation
- Multi-link communication for extreme URLLC (industrial applications)
- Cross-link interference management

These are topic areas that have the potential to create new offers or substantially enhance existing products. Their exploitation can be either by an SME offer, or they can become part of a product line in the large industry.
Also, in order to promote innovation beyond the project's scope, ONE5G established an Advisory Board consisting of leading companies in the field of telecommunications and related industries like automotive and automation which were interested to gain knowledge about the project's solutions and at the same time share their opinions about the creation of value and exploitation from the project's results. Main solutions and findings have been already presented to the members. Apart from the ties from the Advisory Board, the project also established and maintained synergies among other related projects (e.g., in the context of 5G-PPP and beyond), in order to exchange useful input and output which in turn maximized the awareness of ONE5G key results and innovation to the overall R&D community.

3.6 Impact

The project has and will continue to have an impact on various levels of the communications industry, the industry overall and the society. This has been addressed along the previous sections, and in the following we will provide an overview.

3.6.1 Impact on research

One of the outstanding outcomes of ONE5G is its publication record with more than 141 publications. In fact, ONE5G partners have contributed to the major international flagship conference as well as the major IEEE journals. Moreover, in addition, as outlined in the dissemination work package, ONE5G has managed to establish a workshop series in the major (and highly competitive) IEEE GLOBECOM and IEEE WCNC conferences. All of this has provided maximum visibility in the respective research communities clearly making ONE5G a standard reference. As an example and highlight, ONE5G has leveraged several ground-breaking and well perceived key results in the field of Massive MIMO for MTC (papers in IEEE TWC and a joint paper in IEEE Access), particularly with the application of advanced signal compressing (such as Compressed Sensing). This is complemented with contribution to CRAN signal processing outlining limits and design criteria for upcoming 5G Advanced systems. Finally, it is emphasized that ONE5G has been one of the first to apply state-of-the art

Machine Learning tools to the system design which will be followed up and clearly influence the respective H2020 (and beyond) research agendas.

3.6.2 Impact on standards

3GPP

Main landing zone for the project are the activities of 3GPP. By the start of the project, 3GPP was preparing release 15 which is the first release having specifications targeting IMT2020 (5G). The main ambition for the project is to help moving 5G towards 5G-advanced (targeting release 16 and 17). Naturally, the end of the project does not stop the industrial partners of ONE5G to contribute to 3GPP making use of the outcomes of the project.

The following working groups of 3GPP are the most relevant for the project to contribute to:

- RAN1 (Radio Layer 1) dealing with the specification of the physical layer of the radio Interface for UE, UTRAN, Evolved UTRAN, and beyond; covering both FDD and TDD modes of the radio interface
- RAN2 (Radio Layer 2 spec, Radio Layer 3 RR spec) dealing with Radio Interface architecture and protocols (MAC, RLC, PDCP), the specification of the Radio Resource Control protocol, the strategies of Radio Resource Management and the services provided by the physical layer to the upper layers.
- RAN3 being responsible for the Overall UTRAN/E-UTRAN architecture and the specification of protocols for the Iu, Iur, Iub, S1 and X2 interfaces.

The project partners contributed to 3GPP through submission of 51 Tdocs. The list of documents is reported in Table 6-1. Section 3.5.3 presents the different technical components developed in ONE5G and which have either impacted 3GPP (Release 15 or relevant Work Items / Study Items of Release 16) or are potential candidate for the next releases, Release 17 and 18.

NGMN

ONE5G (prepared by Javier Lorca Hernando, Telefónica I+D) has actively participated at the NGMN forum (October 25th-26th in Seattle, USA). The title of the presentation has been "Use Cases for Vertical Industries: the ONE5G Perspective" and has included our activities and outcomes in work package 2 of the project with respect to our perspective on relevant use case for vertical industries to be served by 5G.

ONE5G was also referenced in the NGMN document "Extreme Long Range Communications for Deep Rural Coverage (incl. airborne solutions)" [NGMN19].

ITU

In 2018 ITU started the evaluation process of candidate specifications with respect to IMT2020 compliance. 3GPP (and potentially other groups) submitted its New Radio specifications (release 15). 5G PPP as a whole participate to this evaluation activity, while the actual evaluation work is planned to be done by selected projects (ONE5G being one of those). ONE5G calibrated the project-level system simulator, managed by WINGS, to fit to ITU-R requirements and evaluation framework. ONE5G was in charge of assessing 3GPP submission with respect to the connection density KPI. A summary of results is included in Deliverable [D2.3] .

3.6.3 Impact on operators

By providing a technical basis for the enhancement of the 5G system beyond Broadband, ONE5G has made significant contribution for the efficient use of wireless technologies in new areas. Existing operators can benefit from the enhancements made to the broadband system, and from a better control of the quality of experience. They can bring out new offers to their existing customer and acquire new types of customers, for instance in the automotive area or relating to services that rely on mMTC type traffic.

In addition to the classical network operators, the flexibility of the 5G network will bring up new types of network operators: Classical industry sectors like production, logistics, agriculture and media productions will massively benefit from the extensions that have been brought out by ONE5G, they will be able to improve productivity and enhance safety by setting up dedicated local wireless networks with the service profiles that they need.

Beyond this, technologies like network slicing that allow to efficiently support multiple services within the same 5G system and the sharing of spectrum and network resources will have a large impact on the cost of ownership for each service, in rural areas as well as for dense micro-cell deployments. Industry will be able to introduce new services more flexibly with a lower economic threshold.

3.6.4 Societal impact

While a broad part of the society will be able to enjoy better service coverage and an improvement in the Quality of Experience from the improvements made to the broadband pat of the system with better Internet and multimedia connections. But it will be especially the new service types that will change our lives in the coming years. Public safety will rely on the control of critical infrastructure like the grids for electricity, water and gas via wireless links relying on the mMTC and URLLC type links that ONE5G has brought forward. Public safety authorities will be enabled to set up temporary communications networks in response to emergency situations. Use of the new types of communication within the “Smart City” will help to control, optimize and reduce the traffic.

Another significant contribution from the ONE5G project addresses the network energy consumption. Technologies like hybrid antenna arrays or network slicing and sharing directly address the energy consumption. The new service types will allow to better control processes in other areas like production and logistics, allowing for net energy savings there.

The studies on an economic coverage of underserved areas clearly can improve the future availability of wireless services, reducing the digital divide in Europe and in other areas of the world. Already today, internet access and multimedia with good bandwidth and latency are crucial for the participation of people in remote areas to the public life, for the education of children and for making business in a competitive way. Improved coverage thus provides one important pre-condition for the economic and societal development in these areas, taking away some of the pressure towards migration and urbanization.

4 Conclusions of the action

ONE5G has designed, evaluated and proposed a large set of extensions for 5G, addressing performance and cost. While the basis has been the initial 5G as defined in 3GPP Release 15, the main target are Releases 16 and 17, extending the system capabilities to include mMTC and URLLC communication.
The work has been conducted looking at two selected environments “Megacities” and “Underserved Areas”, representing corner cases in terms of deployment density.
The project has further selected a set of use cases covering both environments and supporting the three main service categories as defined in 3GPP: enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low-Latency Communications (URLLC) and massive Machine-Type Communications (mMTC).

The analysis was conducted by describing the general functionality and doing a quantitative evaluation using the KPIs as defined in [D2.1]. This has been complemented by a cost analysis, to identify economically viable solutions – especially in the case of the Underserved Areas.

The project has promoted consensus building on the evaluation results for the evolution of 5G with many publications, conference and workshop contributions and in particular by its close link to standardization providing more than 52 standards contributions up to now, which are aiming mainly at the 3GPP releases 16 and 17.

Within ONE5G, we have proposed advanced link technologies for the upcoming 3GPP releases towards the goal of higher throughput and higher connection densities. Massive Multiple-Input Multiple-Output (mMIMO), Centralized Radio Access Network (CRAN) and Non-Orthogonal Multiple Access (NOMA) have been further evolved and methods for advanced link managements have been proposed.

For Underserved areas, the project has conducted extensive techno-economic studies to identify the cost-driving elements, then identified and recommended a set of solutions that help to improve the provision of wireless services in this economically challenging environment.

Much attention has been paid to the quantitative evaluation, validation and demonstration of the proposed extensions, to provide a solid basis for the further evolution of the 5G system.
Besides the partner’s simulation efforts, a project-wide system simulation tool has been developed gradually, and a part of the results are being contributed to the ITU IMT-2020 Working Group. Since the WP5D meeting is scheduled after project end, ONE5G will be prepare the results and contribute them in co-operation with the CLEAR5G

project.

A subset of the technologies has been demonstrated in the five Proof-of-Concepts that were shown in on MWC as well as EUCNC in 2018 and in 2019.

In addition to the PoC and standards contributions, the project has led to 141 publications.

By the end of this project, 5G as a system still is evolving and will continue to evolve over several 3GPP releases - it has not yet reached its final and mature stage compared to the initial 5G targets. Within this process, ONE5G has given a significant boost to the evolution towards a wider set of applications. It has provided many solutions for the new services and opened directions for the future of 5G and the systems beyond.

5 References

[TR23.791] 3GPP TR 23.791, “Study of enablers for Network Automation for 5G”

[TR26.944] 3GPP TR 26.944, “End-to-end multimedia services performance metrics”.

[TR32.862] 3GPP TR 32.862, “Study on Key Quality Indicators (KQIs) for service experience”

[TS37.340] 3GPP TS 37.340 NR; “Multi-connectivity; Overall description; Stage-2“

[TS38.101] 3GPP TS 38.101 “NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone “

[TS38.133] 3GPP TS 38.133 NR; “Requirements for support of radio resource management “

[TS38.211] 3GPP TS 38.211 “NR; Physical channels and modulation”

[TS38.213] 3GPP TS 38.213 “NR; Physical layer procedures for control “

[TS38.214] 3GPP TS 38.214 “NR; Physical layer procedures for data “

[TS38.214 ED] 3GP214 P TS 38.“NR; Physical layer procedures for data “, V15.0.0 (early drop, approved at RAN#78 meeting)

[TS38.300] 3GPP TS 38.300 “NR; Overall description; Stage-2v

[TS38.304] 3GPP TS 38.304 NR; “User Equipment (UE) procedures in idle mode and in RRC Inactive state “

[TS38.321] 3GPP TS 38.321 “NR; Medium Access Control (MAC) protocol specification “

[TS38.331] 38.331 “NR; Radio Resource Control (RRC); Protocol specification “

[TR38.801] 3GPP TR 38.801 “Study on new radio access technology: Radio access architecture and interfaces “

[TR38.812] 3GPP TR 38.812 “Study on Non-Orthogonal Multiple Access (NOMA) for NR “

[TS38.824] 3GPP TS 38.824 “Study on physical layer enhancements for NR ultra-reliable and low latency case (URLLC) “

[TR38.825] 3GPP TR 38.825 “Study on NR industrial Internet of Things (IoT) “

[TR38.840] 3GPP TR 38.840 “Study on UE power saving in NR “

[TR38.874] 3GPP TR 38.874 “NR; Study on integrated access and backhaul

[TR38.913] 3GPP TR 38.913 “Study on scenarios and requirements for next generation access technologies “

[RP-180669] “New SID on NR mixed mode broadcast/multicast”

[RP-181349] “Revision of SID on integrated access and backhaul for NR”

[RP-181403] “Revised SID: Study on 5G Non-Orthogonal Multiple Access”

[RP-181453] “New Draft WI proposal on NR MIMO enhancements”

[RP-181463] “New SID: NR Power Consumption”

[RP-181469] “New WID proposal on DC and CA enhancements”

[RP-181477] “New SID: Physical Layer Enhancements for NR URLLC”

[RP-181479] "New SID: NR support for Industrial IO"
[RP-182075] "Summary of offline discussion about handling overlapped Rel-16 items for URLLC"
[RP-182806] "New WID on NR-based Access to Unlicensed Spectrum "
[RP-190711] "New work item: 2-step RACH for NR"
[5GPPP-ARCH] "5GPPP Architecture Working Group, White paper "View on 5G Architecture", Version 2.0, December 2017"
[D1.1] ONE5G Deliverable D1.1, "Annual report"
[D2.1] ONE5G Deliverable D2.1, "Scenarios, KPIs, use cases and baseline system evaluation", November 2017.
[D2.2] ONE5G Deliverable D2.2, "Deliverable on the preliminary simulation results for the validation and evaluation of the developed solutions and techno-economic analysis"
[D2.3] ONE5G Deliverable D2.3, "Deliverable on final system-level evaluation and integration and techno-economic analysis"
[D3.1] ONE5G Deliverable D3.1, "Preliminary multi-service performance optimization solutions for improved E2E performance", April 2018.
[D3.2] ONE5G Deliverable D3.2, "Recommended multi-service performance optimization solutions for improved E2E performance"
[D4.1] ONE5G Deliverable D4.1, "Preliminary results on multi-antenna access and link enhancements", April 2018.
[D4.2] ONE5G Deliverable D4.2, "Final results on multi-antenna access and link enhancements", June 2019.
[D5.1] ONE5G Deliverable D5.1, "Definition of the PoCs scenarios", January 2018.
[D5.2] ONE5G Deliverable D5.2, "Final report on implementation and integration of PoC components into the PoCs and final PoC results"
[IR2.1] ONE5G Internal Report IR2.1, "System-level implementation including details on enabling technologies", May 2018.
[IR5.1] ONE5G Internal Report IR5.1, "Preliminary report on implementation and integration of PoC components", May 2018.
[MWC2019_video] video from the 2019 demo booth: https://one5g.eu/wp-content/uploads/2019/03/one5g-@-mwc19_compressed.mp4
[NGMN19] NGMN Technical document « Extreme Long Range Communications for Deep Rural Coverage (incl. airborne solutions) », June 2019, https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2019/190606_NGMN_5G_Ext_Long_Range_D1_v1.7.pdf

[ONE5G_web] ONE5G project website https://one5g.eu/

6 Annex: List of 3GPP contributions

Table 6-1 - List of 3GPP contributions

Title of the contribution	Meeting identifier	Date of meeting	Document number	Involved partner(s)	Status
Sectorized uniform planar arrays versus stacked uniform circular arrays	RAN WG1 NR Ad Hoc Meeting #3	September 18th-21st 2017	R1-1716629	HHI	Submitted
Remaining details of NR-PDCCH structure	RAN1 NR Ad-Hoc#3	September 18th-21st 2017	R1-1716305	Intel	Submitted
Remaining details of NR-PDCCH structure	RAN1 #90b	October 9-13th, 2017	R1-1717378	Intel	Submitted
Discussion on UE assistance/reporting for NR	RAN1 #91, Dec. 2017	November 27th – December 1st 2017	R1-1720287	SEUK	Submitted
Discussion on transition between NR network coordination schemes	RAN1 #90b	October 9-13th, 2017	R1-1717602	SEUK	Submitted
Discussion on UE-to-UE cross-link interference management and measurement	RAN1 NR Ad Hoc#3	September 18th-21st 2017	R1-1716034	SEUK	Submitted
Preliminary system level evaluation for NCJT in NR	RAN1 NR Ad Hoc#3	September 18th-21st 2017	R1-1715937	SEUK	Submitted
Discussion on transition between NR network coordination schemes	RAN1 NR Ad Hoc#3	September 18th-21st 2017	R1-1715936	SEUK	Submitted
Remaining details of NR-PDCCH structure	RAN1 #91	November 27th – December 1st, 2017	R1-1720081	Intel	Submitted
Remaining details of NR-PDCCH structure	RAN1 NR AH#1801	January22-26th, 2018	R1-1800321	Intel	Submitted
Remaining details of NR-PDCCH structure	RAN1 #92	February 26th – March 2nd, 2018	R1-1802406	Intel	Submitted

Considerations on NOMA transmitter	RAN1 #92	February 26th – March 2nd, 2018	R1-1802027	NOK-GE	Sub mitted
Receiver considerations for UL NOMA	RAN1 #92	February 26th – March 2nd, 2018	R1-1802028	NOK-GE	Sub mitted
Essential procedures to be discussed with NOMA	RAN1 #92	February 26th – March 2nd, 2018	R1-1802029	NOK-GE	Sub mitted
Considerations on NOMA evaluation	RAN1 #92	February 26th – March 2nd, 2018	R1-1802030	NOK-GE	Sub mitted
CR to 38.300 on functionality related to 38.21x	RAN1#92bis	April 2018	R1-1805141	NOK-DK	Sub mitted
Considerations on NOMA transmitter	RAN1#92bis	April 2018	R1-1804462	NOK-GE	Sub mitted
Receiver considerations for UL NOMA	RAN1#92bis	April 2018	R1-1804463	NOK-GE	Sub mitted
Procedures to be considered for NOMA operation	RAN1#92bis	April 2018	R1-1804464	NOK-GE	Sub mitted
Considerations on NOMA evaluation	RAN1#92bis	April 2018	R1-1804465	NOK-GE	Sub mitted
Consideration on NOMA study	RAN1#92bis	April 2018	R1-1804466	NOK-GE	Sub mitted
Issues on PTRS	RAN1#92bis	April 2018	R1-1804367	SEUK	Sub mitted
Consistent support of RRC_INACTIVE	RAN2#102	May 2018	R2-1806937	NOK-DK	Sub mitted
Considerations on NOMA transmitter	RAN1 #93	May 2018	R1-1806930	NOK-GE	Sub mitted
Receiver considerations for UL NOMA	RAN1 #93	May 2018	R1-1806931	NOK-GE	Sub mitted
Procedures to be considered for NOMA operation	RAN1 #93	May 2018	R1-1806932	NOK-GE	Sub mitted
Further considerations on NOMA evaluation	RAN1 #93	May 2018	R1-1806933	NOK-GE	Sub mitted
Initial link level	RAN1 #93	May 2018	R1-	NOK-GE	Sub

simulation results for NOCA			1806934		mitted
Initial system level simulation results for NOCA	RAN1 #93	May 2018	R1-1806935	NOK-GE	Sub mitted
Issues on PT-RS Design	RAN1 #93	May 2018	R1-1806724	SEUK	Sub mitted
On UL inter-UE multiplexing between eMBB and URLLC	RAN1#94	August 2018	R1-1808569	NOK-DK	Sub mitted
CQI reporting mode enhancements for URLLC	RAN1#94	August 2018	R1-1808575	NOK-DK	Sub mitted
CLI management in NR IAB	3GPP RAN1 #94	20-24 Aug 2018	R1-1808774	SEUK	Sub mitted
RRC processing delay for RRC Resume	RAN2#103	August 2018	R2-1812395	NK-DK	Sub mitted
CSI Enhancements for MU-MIMO	RAN1#94-Bis	October 18	R1-1811406	NK-GE	Submi tted
Evaluation methodology for UE power consumption	RAN1#94-Bis	October 18	R1-1811478	Nokia	Submi tted
Resource Efficient PDCP Duplication	RAN2#104	12-18 November 2018	R2-1817582	Nokia	Sub mitted
On PDCP Duplication Enhancements with Combination of DC and CA	RAN2#104	12-18 November 2018	R2-1817583	Nokia	Sub mitted
On Resource Efficient PDCP Duplication	RAN3#101b is	8-12 October 2018	R3-185547	Nokia	Sub mitted
Selective duplication upon transmission failure	RAN3#102	12-18 November 2018	R3-186693	Nokia	Sub mitted
Solution for UL inter-UE multiplexing between eMBB and URLLC	RAN1 #95	November 18	R1-1813117	NOK/AAU	Submi tted
On Configured Grant enhancements for NR URLLC	RAN1 #95	November 18	R1-1813118	NOK/AAU	Submi tted
"Discussion on 2-step RACH for NR"	3GPP TSG RAN WG1 Meeting	25.02. - 01.03. February	R1-1903186	HHI	For discus sion

	#96, Athens, Greece	2019			
Remaining details of UL inter-UE eMBB and URLLC multiplexing	RAN1#96	Feb-2019	R1-1901951	NOK-DK	Submitted
Solution for UL inter-UE multiplexing between eMBB and URLLC	RAN1-AH-1901	Jan-2019	R1-1900931	NOK-DK	Submitted
Comparison of DRX with WUS and GTS schemes	RAN1#96	Feb-2019	R1-1903133	NOK-DK	Submitted
Initial evaluation results and consideration on DRX settings	RAN1-AH-1901	Jan-2019	R1-1901187	NOK-DK	Submitted
Selective duplication upon transmission failure	RAN3#103	Feb-2019	R3-190217	NOK-DK	Submitted
Resource Efficient PDCP Duplication	RAN2#105	Feb-2019	R2-1901351	NOK-DK	Submitted
RLC Entity Configuration and Activation for PDCP Duplication Enhancement	RAN2#105	Feb-2019	R2-1901352	NOK-DK	Submitted
Enhancements for Uplink PDCP Duplication	RAN2#105	Feb-2019	R2-1901353	NOK-DK	Submitted