Mobile and wireless communications Enablers for the Twenty-twenty Information Society-II

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METIS-II final project report

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Abstract
METIS-II was an EU co-funded project that started on July 1st 2015 and ended on June 30th 2017. This document gives an overview of the achievements in the METIS-II project. It provides the highlights and main results of the project as well as references to the relevant deliverables. The three main results of the project are 1) 5G Overall RAN design based on novel technology components 2) Evaluations of the 5G KPIs and the definition of the associated evaluation methodology 3) Development of a 3D visualization platform for easy demonstration and interaction with project results.

Revision History

Revision	Date	Description
1.0	2017-06-30	First public release

Contents

List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
4G	4th Generation of mobile networks
5G PPP	5th Generation Infrastructure Public Private Partnership
AaSE	AIV-agnostic Slice Enabler
AI	Air Interface
AIV	AI Variant
AN-I	Access Network – Inner layer
AN-O	Access Network – Outer layer
C-RAN	Centralized/Cloud-RAN
CN	Core Network
CP	Control Plane
CPF	Control Plane Function
CU	Centralized Unit
D2D	Device-to-Device
DL	DownLink
DTS	Dynamic Traffic Steering
DU	Distributed Unit
H2020	Horizon 2020
HetNet	Heterogeneous Network
HW	HardWare
ICT	Information and Communication Technology
IM	Interference Management
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
JT	Joint Transmissions
KPI	Key Performance Indicator
LAA	Licensed Assisted Access
LSA	Licensed Shared Access
LTE(-A)	Long Term Evolution (-Advanced)
MAC	Medium Access Control
MANO	MANagement & Orchestration
MC	Multi-Connectivity

MIMO	Multiple-Input Multiple-Output
mMTC	Massive Machine Type Communication
mmW	Millimeter Wave
NF	Network Function
NGMN	Next Generation Mobile Networks
NR	New Radio
PC	Project Coordinator
PDCP	Packet Data Convergence Protocol
PHY	PHYsical layer
PPDR	Public Protection and Disaster Relief
QoS	Quality of Service
RAN	Radio Access Network
RM	Resource Management
RRM	Radio Resource Management
SAC	Spectrum Assignment Coordination
SLA	Service Level Agreement
SME	Small and Medium size Enterprises
SMS	Spectrum Management System
SW	SoftWare
TDD	Time-Division Duplex
TM	Technical Manager
UC	Use Case
UL	UpLink
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
WLAN	Wireless Local Area Network
WP	Work Package
WRC	World Radiocommunication Conference
xMBB	Extreme Mobile Broadband

1 Introduction

METIS-II was an EU co-funded project that started on July 1st 2015 and ended on June 30th 2017. The total project budget was close to 8 M€ and around 100 researchers have worked in the project during the project lifetime.

This document gives an overview of the achievements in the METIS-II project. It provides the highlights and main results of the project as well as references to the relevant deliverables so that the interested reader can probe further.

1.1 Main achievements of METIS-II

If one has to summarize the project in three bullets the following are the three main results:

- 5G Overall RAN design based on novel technology components
- Definition of the 5G KPIs, development of the evaluation methodology and evaluation of the METIS design vs. the KPIs
- Development of a 3D visualization platform for easy demonstration and interaction with project results

The 5G RAN design has now reached a maturity level that is adequate for standardization. Some concepts developed in the early phase of the project have already been included in the first 3GPP release of NR and in the evolution of LTE. Technologies developed later in the project are suitable for later releases. METIS-II has identified eleven key RAN design questions that should be answered to be able to build 5G system, and the developed 5G RAN design responds to these questions, more details are in section 3.

METIS-II has also produced system evaluations of the 5G KPIs in five use cases (UCs). The results show that it is possible to meet almost all of the KPIs using the technologies developed in the project. To be able to conduct the evaluations, the models to be used for all UCs have been specified. In addition, METIS-II has led the work on aligning these models and assumptions across all 5G PPP projects, further details can be found in sections 5 and 6.

Another key achievement of METIS-II is the 3D METIS-II Visualization Platform. The visualization platform allows the user of the platform to interact in real time with some of the most important achievements of METIS-II. For example, it is possible to demonstrate, in a virtual world, how a system based on the 5G RAN design would “feel” for a user in reality, more details can be found in section 8.

In addition to the three main achievement areas highlighted above, METIS-II has also introduced new ways to authorize the use of spectrum, allowing for more dynamic and local use of spectrum, and has designed a holistic functional architecture based on enhanced LSA, c.f. section 4. The economic aspects of deploying 5G has also been studied to determine how to best roll out 5G, c.f. section 7.

1.2 The main 5G services

For 5G the envisioned services can be grouped into three main categories. For the remainder of the document it is expected that the reader is familiar with these services:

xMBB for extreme Mobile Broadband: Human-centric use cases for enhanced access to multi-media content, services and data with improved performance and increasingly seamless user experience. This usage scenario covers a range of cases with different requirements, e.g., the hotspot case with high user density, very high traffic capacity and low user mobility, as well as the wide area coverage case with seamless radio coverage providing much improved user data rate compared to existing data rates with medium to high user mobility. This service is also referred to as eMBB, for enhanced Mobile Broadband.

Ultra-reliable and low latency communications (URLLC): Stringent requirements for capabilities such as throughput, latency and availability, although not necessarily simultaneously. Examples: Wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc. This service is also referred to as uMTC, for ultra-reliable machine-type communication (MTC).

Massive machine type communications (mMTC): Characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost, and have a very long battery life.

2 Consortium Setup

The consortium consisted of 23 partners, with vendors, operators, research institutes and academic institutions in the mobile industry. When composing the consortium care was taken to including the main influencers in the industry. Another aspect considered was to ensure continuity from the METIS project. Many partners have been involved in almost all tasks while some have specialized in a few areas. It is impossible to list all achievements of all partners here. However, we provide some highlights to give an idea how the tasks have been distributed in the project. The details of each partner’s engagement can be found in the periodic reports [MII-P1][MII-P2][MII-D74].

The vendors in the consortium were Ericsson, Huawei, Intel, Nokia and Samsung. In the beginning of the project three Nokia sites were involved and in addition at the start of the project Alcatel Lucent was a partner. Following the acquisition of Alcatel-Lucent by Nokia they became the fourth Nokia site. Toward the end of the project this acquisition triggered restructuring of Nokia research with resulting in closure of the research activities at the Poland site. Ericsson, Nokia, Huawei and Samsung have taken on the role as WP leaders, Nokia have taken on the TM (Technical Manager) role and Ericsson has been the PC (Project Coordinator).

From the operator community, Deutsche Telekom, DOCOMO, Orange, Telecom Italia and Telefonica have been participating. Orange has been the leader of WP1 and has contributed significantly to the techno-economic studies. Telecom Italia has lead the dissemination WP (Work Package), i.e. WP7. Deutsche Telekom has among other things contributed to the architecture discussions on splits and slicing. DOCOMO Eurolabs has mainly focused on the work started in METIS, i.e. the user plane design. Telefonica has contributed in the spectrum area. The spectrum topics and scenarios have also been topics where the operators have been engaged.

Four research groups from four universities have participated in METIS-II. The two universities in USA have focused on the physical layer aspects (NYU) and worked on RRM aspects (Winlab). University of Kaiserslautern has focused on the visualization work and Universitat Politècnica de València have supported the project with visualization work and work in WP4 on the user plane design. In addition, Industrial Technology Research Institute (ITRI) in Taiwan worked on the visualization platform as well.

Two SMEs have been in the project. The special competence of IDATE is in the spectrum and techno-economic field and they have contributed to the results from the studies done WP1. The other SME, Janmedia, is specialized on graphical design and designing visualizations. They have been the main contributor and developer of the visualization platform. One outcome of METIS-II worth highlighting is that Janmedia and possibly also other partners will provide support for the visualization tool as part of their service portfolio after the project end.

In addition to the partners in the consortium the project has been supported by an Advisory board consisting of representatives from academic institutions (University of Southampton, University of Surrey, TU-Dresden, Politechnico di Torino and Kapodistrian University of Athens), from industry (Keysight, BMW, Bosch, Thales and Qualcomm) and from the standardization/regulatory world (OFCOM, ANFR and ETSI). The advisory board have provided feedback on results and direction of the project during the project lifetime.

Although the project primarily has been an European endeavour, METIS-II has ensured a global footprint with the inclusion of partners from other regions. The Huawei and DOCOMO headquarters have for example provided insights and feedback on the scenarios and use cases from a Chinese and Japanese perspective respectively. ITRI have used the opportunity to share what Taiwan is doing in the 5G area and by providing further collaboration opportunities. NYU and Winlab have provided links into the research community in USA.

The consortium has had a large degree of diversity in geography, competence and background. This has sometimes made setting up meetings and collaborating across cultural borders challenging but ultimately this diversity has also heavily contributed to the success of the project. The widespread networks of all the partners have made it easy to share ideas and also capture influences from the entire world. The diverse backgrounds have also made it possible to get different views on the problems which ultimately has led to better solutions with great technical depth. Finally, the networks built by the persons participating in the project will continue to contribute to the future success of Europe in the race towards 5G standardization.

3 5G RAN Design

METIS-II has provided the 5G RAN design [MII-D24][MII-D42][MII-D52][MII-D62] underlying the 5G air interface and the definition of a framework for the harmonization and integration of the different Air Interface Variants (AIVs) [MII-D42]. The framework supports both AIVs optimized for a specific service and general purpose AIVs including LTE(-A). This integration is done at RAN level, it allows the reuse of most network functions and it foresees a common RAN-CN interface.

The 5G RAN design describes the logical split between RAN and Core Network (CN) together with the interfacing options. It investigates if functions like mobility and paging, which in current networks are located in the Core, can be moved from Core to RAN to better support new 5G services. A framework for agile resource management is also included.

An analysis of the split options that exist in the RAN has been carried out for the both the control and user plane enabling deployment options ranging from fully centralized to fully distributed topologies.

In the RAN design for 5G a novel system concept has been designed for spectrum management and sharing as well as a holistic functional architecture to support this. This concept is further enhanced by additional enablers like context awareness or QoS. The use of spectrum databases (similar to enhanced LSA) is foreseen, with interfaces to network and resource management.

At the start of the project 11 fundamental design questions were formulated. These questions capture the hardest problems that need to be solved in a 5G RAN design. Table 3-1 lists these design questions together with the answers found by METIS-II.

Table 3-1: METIS-II answers to the key 5G RAN design questions.

No	Key RAN Design Aspect / Question
1	**What is the general spectrum usage foreseen for 5G?** 5G networks have to integrate numerous frequency bands within a wide range of spectrum and bands with differing spectrum authorization schemes. Frequency bands for 5G and a concept for spectrum management and sharing are briefly introduced in [MII-D24]. More details can be found in [MII-D31] and [MII-D32].
2	**Given the various characteristics of different spectrum bands, which band should be used for what type of service, air interface and how much spectrum needs to be made available for mobile communications in the different bands?** The mapping of service requirements and air interface variants (AIVs) to specific spectrum ranges is detailed in [MII-D31] and [MII-D41]. A brief summary is also available in [MII-D24]. The amount of spectrum needed in different bands is discussed in [MII-R31] with more detailed analysis in [MII-D32].

3	**Which air interface variants are expected to be introduced in the context of 5G, and which are to be evolved from existing standards?** An AIV for below 6 GHz is expected to be an evolution of current 4G standards. Filtering may be applied for reduced in-band interference. The subcarrier spacing, symbol duration and slot duration can be adapted to the use case, e.g. shorter symbols may be chosen for low latency traffic. The case of D2D communications may require special waveforms to counteract the effects of asynchronicity. Above 6 GHz new AIVs with special frame structures may be required to, e.g., manage massive MIMO and channel estimation. Vehicular communications, especially for road safety, may require new AIVs to efficiently deal with multicasting, asynchronicity and reliability.
4	**How many different novel and legacy air interface variants should different devices support?** **Which forms of concurrent connectivity (e.g. multi-standard and multi-cell connectivity, concurrent device-to-device and device-to-infrastructure connectivity) will be required in 5G?** This will depend on the purpose of each device. Thus an important requirement is that the harmonized 5G AI should allow that purpose-specific devices only implement necessary functionalities. Concurrent connectivity in the form of MC (e.g., multi-AIV connectivity) or concurrent D2D and device-infrastructure connectivity is beneficial for agile RM. Again the type and need for concurrent connectivity is application dependent. Details are provided in [MII-D24]. Possible implications of concurrent connectivity on the device complexity are captured in [MII-D52].
5	**How tightly are novel air interface variants expected to be integrated with each other and with legacy technologies (e.g. LTE evolution and WLAN), to which extent should they be harmonized or have common functionality in the protocol stack, and on which level should different transmission forms be aggregated?** The integration among legacy AIV (LTE-A evolution) and novel AIVs, or the integration among multiple novel AIVs, should be possible on RAN level [MII-D52] [MII-D62]. PHY harmonization of novel AIVs in the form of multi-waveform implementation may be a feasible option if necessary since it decreases the implementation complexity and required chip space compared to implementing separate functionality for multiple waveforms. The coexistence of different numerologies and frame structures may be required to better support different service characteristics [MII-D42]. The harmonization level in the protocol stack must be carefully selected to allow sufficient backward compatibility. For LTE-A evolution and novel AIVs PDCP layer aggregation is seen as feasible [MII-D24]. Among novel AIVs, a large extent of protocol stack function harmonization should be strived for (i.e. at least a harmonized MAC and higher layers) [MII-D41]. The interworking with other access technologies, such as WLAN can be performed via radio maps, e.g., to determine transmit power levels [MII-D52]. Further, the use of

	unlicensed band in an LAA manner is analysed in dynamic radio topologies [MII-D52].
6	**How can one efficiently handle interference in an ultra-dense environment?** **What kind of information is required, at what time scale and how fast must the system react?** The way of handling interference depends on the operational scenario and use case [MII-D52]. To handle the same-entity interference in dynamic TDD operation joint transmissions (JT) with dummy symbols is found to provide a good trade-off between UL and DL performances. To overcome the pilot contamination in dynamic TDD with massive MIMO, dynamic selection of transmission paths should be supported. These schemes are applied on a subframe basis, e.g., few ms. Furthermore, interference resistive design can be exploited to mitigate inter-cell interference, where coordination is needed on the X2* interface. The concept of lean design for common signals reduces the amount of interference, which is an important enabler for the 5G system to handle ultra-dense environments [MII-D24]. The IM schemes should be adaptive to cope with the dynamic radio network topologies based on non-static access nodes. The time scale of modifying the interference mitigation scheme depends on the changes of the topology, which can range from minutes to hours.
7	**What will be considered as “resource” in a 5G system?** **How can we manage these resources effectively in order to achieve the 5G KPIs?** It is envisioned that the notion of a resource is extended beyond conventional. With respect to how this extended notion of resource will be managed efficiently, various considerations have been presented in [MII-D52], including mechanisms pertaining to IM, RAN moderation, DTS and multi-slice RM. In addition to the licensed radio frequency bands, the extended realm of resources includes the unlicensed bands, whose usage shall be adaptive and be coupled with the changing radio network topology, energy, as well as HW and SW resources.
8	**On which time scale should certain 5G radio access network functionality (e.g. radio RM, radio resource control, mobility) operate, and consequently, how should the necessary functionalities be best abstracted, grouped and tackled in standardization and implementation?** Various 5G functionalities are envisioned to be handled on a faster time scale than in legacy systems. The METIS-II RAN design enables mobility and MC among LTE-A evolution and novel 5G AIVs on RAN level, inherently allowing for a faster setup of new MC constellations and switching among these[MII-D24]. The proposed DTS among different AIVs, which was so far done via hard handover, is performed on lower protocol stack layers and consequently on a much faster time scale. The envisioned agile RM framework groups RM mechanisms under intra-AIV and AIV-

	overarching RM functionality framework, see [MII-D24]and [MII-D52]. The mechanisms pertaining to AIV-overarching RM are envisioned to be implemented in a centralised unit (AN-O) while intra-AIV RM schemes are envisioned to be implemented in distributed units (AN-I).
9	**How will the concepts from dynamic spectrum management interwork with the control plane architecture (new network elements and interfaces for this purpose and/or some level of integration to the control plane design)?** The METIS-II architecture concept embraces the regulator domain covered by a “Spectrum Management System” (SMS), and the operator domain which consists of a central Spectrum Assignment Coordination (SAC) entity supported by a number of further functional blocks (see [MII-D24]). The SAC is going to be integrated into the 5G Network MANO framework. More details can be found in [MII-D32].
10	**What will be the network elements and interfaces in the 5G system architecture and, assuming these, how would these interfaces look like, i.e. which functionalities will they have, which programmability level will be adopted, what level of openness, what level of abstraction, etc.?** In 5G the RAN NFs may be distributed across different network elements in a centralized or a distributed way (CU vs. DU) according to the service demand to be supported. In each unit the NFs can be split into a CP part (CPFs) and a UP part (UPFs). On the interface between RAN and CoreCN, the UP may not be transported over a single protocol as in 4G but each service or slice may use the protocol (e.g. GTP, GRE, EoGRE, ETH) best suited for the service. For the intra-RAN interfaces, it is assumed that an evolved X2* interface between access nodes is required. It is expected that this interface will also be crucial for agile IM in 5G [MII-D52]. Furthermore, a hierarchical CP design is envisioned, where AIV-agnostic control schemes are implemented at a CU, while AIV-specific control schemes are located at the DUs. Accordingly, a new x-haul interface between the CU and DUs is crucial to attain the promising gains of the developed mechanisms. New signalling schemes are then required for multi-AIV resource mapping, as summarized in [MII-D24]. The AIV-specific radio link feedbacks depend on the AIV (e.g., carrier frequency) and UE context (e.g., speed) [MII-D52].
11	**What type of control and user plane functionalities should be centralized or distributed depending on the 5G use cases associated to them? Out of these functionalities, what are the most promising candidates to be implemented as virtual network functions?** The CPFs regarding AIV-overarching RM are envisioned to be implemented in a CU [MII-D24]. These centralized functions enable efficient mapping of the service flows to the appropriate AIVs. Also, multi-slice RM requires AaSE functionality to be centralized so that SLAs can be fulfilled despite changing network conditions. The corresponding UPFs should be centralized accordingly (e.g., centralized PDCP processing is required in case of the aforementioned AIV-overarching RM). AIV-specific CPFs, such as, dynamic scheduling and IM, can be implemented in a distributed way. Nevertheless, RM mechanisms can also be implemented in a centralized way provided that the physical deployment allows such a centralization, e.g., C-RAN

	deployments. Besides the above-mentioned strategies for function placement, a flexible network architecture is of importance. With the help of different options for centralization (a lower / higher degree of centralization, as described in [MII-D24]), the network can be adapted to fully exploit the underlying transport network.

4 Spectrum

Success of 5G depends on access to a sufficient amount of contiguous, wide and globally harmonized new frequency bands. Based on several initiatives and trials in different countries, the first 5G implementations are expected to take place in the 3.4-3.8 GHz range and in the 26 GHz and 28 GHz bands.

For xMBB usage scenarios, a mixture of frequency spectrum is required. Lower bands provide coverage and support low traffic, while higher bands with large contiguous bandwidth are used to cope with extreme traffic demand, including wireless backhaul solutions, Exclusive licensed spectrum is essential to guarantee coverage and service quality. This is supplemented by spectrum access with other licensing regimes, e.g. Licensed Shared Access (LSA) or license-exempt access), to increase the overall spectrum availability. For most mMTC applications, spectrum below 6 GHz is more suitable and spectrum below 1 GHz is needed in particular when large coverage areas and outdoor to indoor penetration are needed. Exclusive licensed spectrum is the preferred option. However, other licensing regimes might be considered depending on the specific application requirements. For URLLC services, licensed spectrum is considered to be most appropriate. For automotive traffic efficiency and safety communications, the spectrum harmonized for Intelligent Transport Systems (ITS) is an option. Spectrum below 1 GHz is particularly suited for high-speed applications (like high-speed trains) and for rural environments.

The bandwidth demand for 5G services depends on a number of factors, including the use case, the applications used, the deployment scenario, the frequency band, user density and spectrum efficiency. For example, with specific assumptions a total bandwidth demand of 2.4 - 7.1 GHz has been estimated for the xMBB use case “dense urban information society”. It is evident that a significant amount of additional spectrum needs to be made available for 5G and if possible harmonized world-wide. This is addressed by a group in ITU-R which is conducting sharing and compatibility studies for a number of frequency bands in the range 24-86 GHz in order to prepare for a possible identification for 5G/IMT-2020 at the World Radiocommunication Conference in 2019 (WRC-19).

The concept for spectrum management and spectrum sharing for 5G mobile networks developed in the METIS-I project was enhanced in METIS-II to also cover radio spectrum already designated for potential new 5G user groups, e.g. for vertical industry applications such as ITS or PPDR. The technology components for flexible spectrum usage developed in METIS-I were complemented by additional technical enablers, e.g. covering application context awareness and QoS driven scheduling [MII-D31].

To enable the spectrum management concept, a holistic architecture is introduced, embracing the regulator domain as well as the operator domain. In the regulator domain, a “Spectrum Management System” (SMS), would process the spectrum resource request and perform protection evaluations and decisions based on regulatory terms and rules. The SMS developed is based on the LSA approach and extended to support several additional sharing methods, e.g. limited spectrum pool. The operator domain is comprising a central “Spectrum Assignment Coordination” (SAC) entity, which takes the final assignment decision. The SAC functionality may be implemented into the network management & orchestration (MANO) framework of the 5G system [MII-D32].

5 Scenarios

In order to be able to design the 5G RAN for the three main 5G services and ensure that they will share the RAN in the most efficient way, the developed technical components and the overall RAN design have to be evaluated for practical use cases. Based on the dozens of use cases available in the literature (METIS project and other EU projects, 3GPP, NGMN, etc.), METIS-II has defined a small number of use cases that are representative of the main services and scenarios [MII-D11]. The relatively limited set eases the evaluation process. Figure 5-1 provides an overview of the complementary requirements and service scopes addressed by each use case and thus describes the motivation for selecting each of them.

It is worth noting that METIS-II lead the 5G PPP activity that harmonized the phase 1 projects’ activities on use cases and performance models. The outcomes of these activities were documented in a white paper issued in April 2016, and updated in June 2017 [5GPPP – UC16].

	Use Case (UC)	Scope of requirements (network/user perspective)	Scope of services (service perspective)	Source
xMBB mMTC	Dense urban information society	Experienced user data rate / Traffic vol. per subscriber / Nb. of users and devices / Energy efficiency	Broad range of communication services covering needs related to both indoor and outdoor urban daily life (excl. office and factory)	METIS-I test case enriched by NGMN UC Mobile video surveillance
xMBB	Virtual reality office	Experienced user data rate / Traffic volume per subscriber / Latency	Broad range of communication services in the (indoor) office context	METIS-I test case
xMBB	Broadband access everywhere	Experienced user data rate / Availability / Mobility / Energy efficiency	Full coverage topic addressing outdoor/indoor communication needs especially in rural areas	NGMN use case 50+ Mbps everywhere incl. METIS-I test case Blind spot
mMTC	Massive distribution of sensors and actuators	Availability / Number of devices / Energy efficiency	Broadest range of IoT services covered	METIS-I test case Massive deployment of sensors and actuators
xMBB uMTC	Connected cars	Latency/ Reliability / Mobility	Strong expectation from the (automotive) industry Belong to the first uMTC services expected to be commercialized	METIS-I test case Traffic efficiency and safety complemented by MBB aspects

Figure 5-1: An illustration of the METIS-II 5G use cases and to which use case family or families these use cases belong to. Further, the scopes in terms of requirements and services are illustrated as well as where each use case originates from.

6 Evaluation results

All the main 5G KPIs defined in H2020 were evaluated in [MII-D23] as well as additional KPIs defined in the beginning of the project. The evaluations have been done using inspection, analytical and simulation-based methods. The method chosen for a particular KPI mainly depends on the nature of the KPI but also to a certain degree on availability of tools.

6.1 Inspection based evaluations

For the KPIs evaluated using inspection we can confirm that all of them are fulfilled by the final METIS-II 5G system [MII-D23]. The KPIs evaluated using inspection are:

- **Bandwidth and channel bandwidth scalability**. The METIS-II system can operate with different bandwidth allocations [MII-D41] and in bands up to 100 GHz [MII-D31].
- **Coexistence with LTE**. The METIS-II 5G RAN has been designed for coexistence with LTE (cf. e.g., RRM schemes or RAN moderation solutions captured in [MII-D51]), and the same spectrum bands can be used by both technologies, which could share resources depending on the specific AI needs. This flexible allocation also enables re-farming of spectrum from LTE to 5G.
- **Deployment in IMT bands**. METIS-II has addressed this KPI through work in [MII-D31].
- **Interworking with 3GPP legacy technologies and 802.11 WLAN**. The METIS-II 5G RAN has been designed to support interworking with 3GPP legacy technologies (cf.

Section 2.3.2 in [MII-D61]) and IEEE 802.11 family of WLANs (cf. Section 6.2 in [MII-D61]).

- **Operations above 6 GHz**. METIS-II addresses this KPI through spectrum-related activities in [MII-D31], e.g. analysis of coexistence with fixed service links operating on mmW, or feasibility studies for outdoor-to-indoor deployment at higher frequencies, as well as through appropriate UP and CP design [MII-D41] [MII-D51] [MII-D61].
- **Spectrum flexibility and sharing**. The ability to adapt to different DL/UL traffic patterns and capacity for paired and unpaired bands has been addressed by METIS-II through specific UP design concepts [MII-D41] and system level solutions. METIS-II has also investigated mechanisms to allow sharing licensed or unlicensed spectrum with other technologies [MII-D31].
- **Support of wide range of services**. This has been addressed by METIS-II through numerous technical solutions in all technical WPs.
- **Low cost requirements**. METIS-II 5G RAN is designed to support low cost devices, as well as low cost operation and maintenance enabled by e.g., mMTC solutions captured in [MII-D23], lean signalling and energy efficiency [MII-D51] [MII-D61], spectrum sharing [MII-D31] and self-organizing networks [MII-D51].

6.2 Analytical evaluations

For the KPIs evaluated using analytical methods it was also concluded that the 5G RAN designed by METIS-II fulfils the 5G system requirements [MII-D23]. A summary can be found in Table 6-1.

Evaluation results indicate that a 5G RAN can deliver peak data rates in the order of 21 Gbps in DL and 12 Gbps in UL. Comparing to 4G operations, 5G RAN designed in METIS-II will also enable significant reduction of UP and CP latencies, down to 0.763 ms and 7.125 ms, respectively. In UP the key enabler for shorter latencies is the reduction of the sub-frame length to 0.125 ms. The CP latency reduction was enabled by a new RRC Connected Inactive state. It has been also shown that for mMTC operations a single battery life time exceeding 10 years is possible for devices that sporadically upload data to network.

Table 6-1: Analysis KPI evaluation.

KPI	Requirement	METIS-II performance	Key contributor
CP latency	< 10 ms	7.125 ms	RRC Connected Inactive, reduction of processing time in BS and UE
UP latency	< 1ms	0.763 ms	Shortening of TTI, reduction of processing time in BS and UE
mMTC energy efficiency	> 10 years on a single 5 Wh battery	> 10 years on a single 5 Wh battery	Extension of DRX, CP latency reduction, deep sleep energy conservation features
Peak data rates	> 20/10 Gbps for DL/UL	21.7/12.4 Gbps for DL/UL	MIMO spatial multiplexing (for lower frequencies), exploitation of mmW bands
Mobility interruption time	0 ms	0 ms	MC + make-before-brake

6.3 Simulation-based evaluations

Finally, the simulation-based evaluation work for the five METIS-II 5G UCs has shown that the METIS-II requirements for 5G [MII-D11] can be fulfilled using a subset of the TeCs proposed in the project [MII-D23]. A summary of the results for the KPIs evaluated using simulation can be found in Table 6-2.

In UC1, for dense urban environment and HetNet deployment, users can expect data rates above 300 Mbps and operators can support traffic volumes greater than 750 Gbps/km^2. In this UC, significant energy efficiency gains have been demonstrated as well.

In UC2, high frequency bands and massive antenna systems enable Gbps data rates indoors, reaching up 7.85 Gbps, which is above the 5 Gbps target.

In UC3, traffic volumes of 700 Mbps and 650 Mbps are supported in DL and UL for the required user data rates of 50 Mbps and 25 Mbps, considering an LTE system at 800 MHz with BF capabilities. With 3.5 GHz, UC3 required data rates can be supported with 10 times higher load. In addition, energy efficiency analysis shows that the system with BF consumes half the energy of the system without BF, when sleeping capabilities are considered.

In UC4, it is shown that, depending on the traffic profile, 5G will cater for more than 1 million devices per km^2. For devices transmitting once every 100 s, the proposed access scheme support more than 6.9 million devices per km^2.

In UC5, although results captured in [MII-D23] were not enough to meet the requirements, the latest incorporation of adaptive transmission schemes made the METIS-II 5G system proposal also reach the defined target. In this sense, reliability provided in urban scenarios for 5 ms end-to-end latency is close to 99.999% for the required range of 50 m with 40 MHz of available spectrum. However, in the highway scenario, the required coverage range of 1000 m can only be achieved with an allocation of 100 MHz to the V2V communication link.

Table 6-2: Simulation KPI evaluation.

KPI	Requirement	METIS-II performance	Key contributor
User throughput (UC1, UC2 and UC3)	UC1: 300 Mbps UC2: up to 5 Gbps UC3: 50/25 Mbps for DL/UL	UC1: 1 Gbps+ UC2: up to 7.85 Gbps UC3: 50/25 Mbps for DL/UL	Only DL values for UC1 and UC2 Different methodology applied for UC3 evaluation
mMTC device density (UC4)	> 1 mln/km^2	4 mln/km^2	Depends heavily on the traffic/report periodicity of mMTC devices. 1 upload of 1000 bits every 100 s was used in METIS-II
Reliability (UC5)	99.999% at 50/1000m for urban/highway	99.999% with 40/100 MHz for urban/highway	Evaluation of V2V solutions with dynamic resource allocation techniques. Required channel bandwidth is identified
Network energy efficiency (UC1, UC3)	Should follow (at least) capacity improvement	For the capacity x1000, network energy efficiency improvements of 350-7500 were reported	Evaluation done only for Dense Urban environment. Savings depend on the load level in LTE-A/5G network

7 Techno-economic evaluations

In order to evaluate the 5G RAN design presented in section 3, the technical performance evaluation of section 6 is not sufficient. There is a need for a techno-economic feasibility analysis, from two perspectives:

Qualitative: where the 5G RAN ecosystem evolutions that are expected with 5G are identified. The evaluation describes the evolutions of the roles of the different actors and analyses the possibilities for new actors to emerge in the ecosystem, due to the technological evolutions, for example RAN virtualization, slicing, URLLC capabilities, massive deployment of small cells, new trends in spectrum usage. This analysis was performed in [MII-D11], describing the new value chains that are expected to emerge in the 5G RAN, and building the value net of mobile network operators.

Quantitative: i.e. a cost benefits analysis for the 5G RAN deployment. This analysis was done in [MII-D12]. Specifically, a 5G market forecast was performed including smartphones and other connected objects and also vertical markets including factory of the future, energy, smart agriculture, media and entertainment, public safety, eHealth and automotive. We then presented an estimated revenue for 5G services based on this market forecast and proposed dimensioning methodologies for both xMBB and mMTC services, taking into account both data and control planes. We also proposed deployment scenarios for joint 4G/5G deployments in different environments. Based on this, a cost-benefit analysis was performed for 5G deployment in dense urban environments and showed the deployment path in 2020-2030 timeframe considering different traffic assumptions. Our results show a positive return on investment in most of the cases in dense urban environment. The analysis also shows that a flat rate pricing strategy for xMBB may result in negative return on investment and may have a negative impact on 5G RAN deployment.

8 Visualisation Platform

In METIS-II [MII-WEB], one of the key objectives is to enable the 5G concepts to reach and convince decision makers from non-ICT industries [MII-D22][MII-WP16][MDB+16]. Thus, it is necessary to have easy-to-understand illustrations of the envisioned 5G use cases and the proposed technical solutions, targeting the non-experts. A professional 3D visualization tool (METIS II Visualization Platform) enabling a viewer to interact with 5G enabled scenarios [MET13-D11][MET15-D15][MII-D11] has been introduced by METIS-II to achieve this and to allow the introduction of simulation driven data to be evaluated.

One of the main purposes of METIS II's Visualization Platform is to communicate 5G RAN Design concepts. They are grouped into Key Innovation Pillars and are tied to one or two WPs. Even in the earlier stages of the platform's development the approach was already present, and the use cases investigated and evaluated in the platform were and are based on this logic. At the final stage of the Visualization platform, where the direct interaction with simulators was introduced, the Key Innovation Pillars are not only considered as the use case scenario origins, but also sets of visual and data driven elements and examples on which the future investigation into the areas of interest can be initiated.

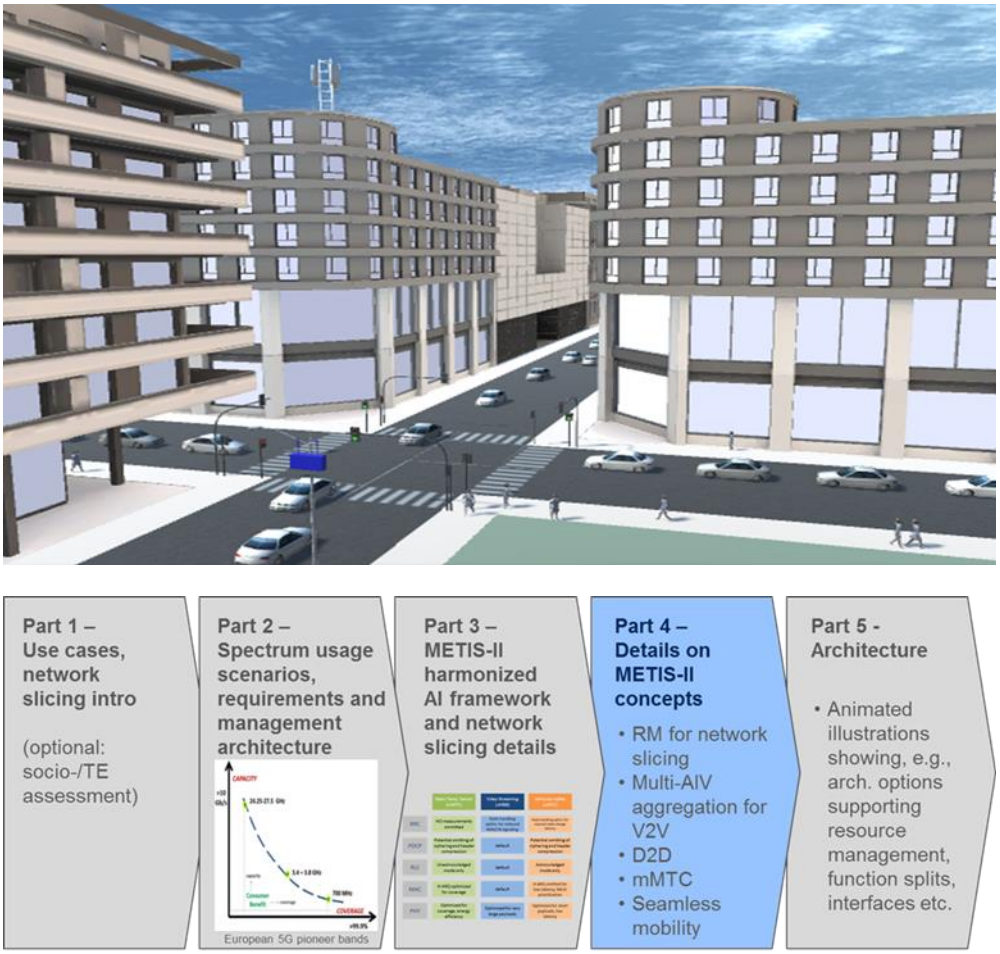

Figure 8-1: The visualization platform and the different parts visualized therein.

The visualization platform has been one of the most important achievements in METIS-II project and was successfully presented in many international events, with a large appreciation from the audience. Being developed in an open mode, the platform can be further extended and improved in the next months and years, possibly within the framework of 5GPPP. The partners that worked on it in the project will continue to work on the next developments internally and in collaboration whenever this will be possible

9 Dissemination activities

The project organized a large number of workshops and conferences in the two-year period of work [MII-D74]. A series of workshops have been organized by METIS-II on the theme of “5G

RAN Design", which is one of the main technical objectives of the project. In May 2016 a first workshop on these topics was organized in ICC2016 in Malaysia and this workshop was well attended at the conference by the research community. The second workshop in the series was held in Globecom2016 in USA, with a good participation as well. The series has been completed with the third iteration at ICC2017 in Paris.

METIS-II was also very active in various conferences. Among the most important ones that were considered for dissemination are VTC Fall in September 2015, a panel session in CSCN15, EuCNC in 2015, 2016 and 2017, PIMRC 2016 in Valencia and Globecom in 2015 and 2016.

In October 2015 the project was invited to be one of the few that showcased the first achievements in the booth of the European Commission at the event ICT 2015 in Lisbon (see **Figure 9-1**). In such event, widely acknowledged as one of the most important in that period, the project presented the visualization platform for the first time.

The same platform, including already some of the innovations brought by the partners working in METIS-II, was one of the demos that METIS-II presented at the Mobile World Congress 2016 (see **Figure 9-2**). Among the papers developed in the project it is worth mentioning a couple of white papers, one on 5G RAN Design, and one on the KPIs to evaluate the new 5G systems.

Figure 9-1: METIS-II at the ICC 2015 booth of the European Commission.

Figure 9-2: METIS-II at Mobile World Congress in March 2016

Figure 9-3: METIS-II at EuCNC in June 2017

Moreover, METIS-II promoted and supported the preparation of a Wiley book on 5G system design, authored by METIS-II participants, with a preface from the European Commission. The book counts more than 100 contributors from many 5G PPP projects and is one of the biggest achievements in the dissemination activities of 5G PPP Phase 1 projects.

The dissemination and the related exploitation activities in METIS-II have been fundamental for the partners involved and for the research ambitions of the project. The role and the momentum of the project received a widespread consideration inside and outside the consortium.

Many of the activities performed in the project have paved the way for a successful start of the 5G standardization process in 3GPP and ITU-R. Fully exploiting the legacy with its parent project METIS, METIS-II successfully published its deliverables and White Papers that are a reference point for any activity related to the 5G RAN design topics.

10 5G PPP interactions

5G PPP is a joint initiative between the European Commission and the European industry that aims at securing Europe's leadership in the particular areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media [5GPPP-WEB]. One of the tasks of 5G PPP is to ensure collaboration between the research projects funded by the European Commission in the 5G area. The vision is that the total outcome of the projects should be larger than the sum of the individual efforts done by the projects.

METIS-II has significantly contributed to and driven cooperation within the 5G PPP framework. The two main efforts are the organization of workshops and the creation of a white paper detailing scenarios and models to be used for evaluation as well as the outcomes of the evaluation of the 5G KPIs.

METIS-II organized a series of workshops within the community of 5G PPP projects. Three of these workshops were directly organized by the project itself, the first one in Kista in September 2015, in conjunction with a project plenary meeting. The second after the project plenary meeting in Valencia in January 2016 and the third one in Athens in February 2017. METIS-II also co-organized the workshop on architecture with mmMagic, Fantastic-5G, 5G NORMA and many other 5GPPP projects that took place in London in March 2017.

The project also drove the activity to align scenarios and KPIs. The goal was to allow projects to use the same or similar models for evaluations so that the results from the projects could be compared and so that the results could be combined to provide an overall of estimation of system performance. Towards the end of METIS-II the results were collected and combined to provide a full picture of the 5G performance. The entire activity is documented in the white paper [5GPPP-UC17] and some of the results are also described in chapter 6. A key to the success has been to offer projects the possibility to participate without forcing them to use any particular model. This way no unnecessary dependencies and delays have been introduced.

There are other workgroups active in 5G PPP as well. The Architecture WG has written two white papers and METIS-II has contributed significant portions of the RAN design to these white papers on architecture [5GPPP-AR16][5GPPP-AR17]. Project members from METIS-II have also been actively supporting the work by taking on editor roles. The Pre-standards WG has been collecting information about the inputs done to standardization bodies and METIS-II have contributed the list of the standards inputs done. In 3G PPP METIS-II has the largest number of references of the 5G PPP projects. 5G PPP also harbours a WG on Spectrum and we have contributed by reviewing and commenting as well as proposing some of the results from METIS-II to be used by the Spectrum WG.

11 Exploitation

One of the clear targets of H2020 is to improve the success of small and medium sized enterprises (SMEs). In METIS-II two SMEs have been participating and contributing with their specialist competences. One SME is Janmedia, based in Wroclaw, Poland. Janmedia specializes in graphic design and visualizations and they have been one of the main contributors and drivers for the METIS-II Visualisation Platform. For Janmedia the benefit of participating in the project is that METIS-II has provided an opportunity to learn about the requirements and technologies in the mobile industry, for example how networks are built and which components and functions that are included. The participation has provided Janmedia with a new set of skills to provide more visualizations for the mobile industry. As a results of the project they have a new service offering providing consultancy services for the visualization platform.

The other SME in METIS-II is IDATE. They specialize in consultancy services and analysis of the mobile and spectrum business landscape. Participation in METIS-II have provided them with data and insights that they can use in the future when providing their services.

METIS-II have provided all partners with an opportunity to share the knowledge in the scientific community. Even if this does not directly translate into larger business this is important for building credibility and contact networks which in the long run provides more sales. The close ties to the scientific community also provides good way to find skilled persons that can be employed.

METIS-II has been an industry oriented project by nature with a large proportion of the partners from the mobile industry. Ultimately METIS-II has provided European operators and vendors an opportunity to exchange views and work toward an industry consensus on the standardization and rollouts of the first 5G networks as well consensus for the coming features that has not been proposed for standardization yet. This has provided the industry and head-start and the opportunity to be early on the market with the first set of products and services and will also provide a lead for the next release(s) of the standard. The METIS-II results and insights on spectrum are used in the preparatory work in ITU-R for the WRC19 conference.

For the vendors the results of METIS-II are incorporated in the products, for example as specific algorithms or protocol implementations. The operators are using incorporating the results when designing the networks and the rollout plan, e.g. the evaluation of the best architecture splits determine how the 5G networks will be partitioned. For the operators METIS-II has been a door opener when setting up experimental activities. The quantitative techno-economic assessment [MII-D12] will be used by the operators to motivate 5G infrastructure investments and build the rolling plan.

More detailed descriptions of how the individual partners will use the results from METIS-II can be found in [MII-D74]

12 Socio-economic impact

It is difficult to quantify the socio-economic impacts from METIS-II. One hurdle is that changes in society and the economies of Europe are influenced by many things and to establish a clear relationship between cause and effect is not trivial and may not even be possible. A second difficulty is that some of the impacts occur years after the project end, innovations that barely are ready in the lab takes years before they reach a broad market penetration and we can see the impacts. However, we can make some general observations and provide some hints on what may occur in the future.

METIS-II and its predecessor METIS have played a large part in defining what 5G is and what capabilities it will have. Of course the project is not solely responsible for the start of 5G and the following development but a large chunk of the credit should go to METIS. Currently we don't fully understand the impact of 5G on society, but this development is coinciding with another large trend where ICT technologies are leaving the confinement of the ICT industry and are starting to impact and transform all other industries. What is clear is that we'll likely see changes on the same scale as the industrial revolution brought.

On a finer level one of the longer term impacts is the students that have learnt about 5G at the participating universities. Education is one of the investments with highest return that society can make. METIS-II has done this in relevant areas. The education occurring for professionals already out of university should not be forgotten either. Strengthening the competence of the various organizations. New knowledge which is usually not available inside the organizations where they work.

The opportunity for people from across various organizations and locations in Europe to get to know each other is also important. This increase the chance of cross breeding, improves mobility of ideas and people. The setup also allows for an informal friendly way of sharing information between suppliers and customers. Thus making the industry of Europe better equipped to take on new challenges.

The consensus obtained in an EU project is good. It provides a platform for industry to drive topics in standardization. This increases the chance for innovations driven in METIS-II to be included which in turn results in more income from license fees.

Ensuring that the industry in Europe has access to qualified personnel and is more agile strengthens the offering from these companies which should be good for jobs in Europe.

13 Conclusions and future outlook

The main achievements of the project are highlighted in this document which should give a good insight into what METIS-II has done during the two-year project lifetime. There are a lot of interesting details in the deliverables where we describe the technologies developed and how the performance compared to contemporary systems. The interested reader is suggested to look into the provided references for more details.

The outcome of the project has a high relevance for industry. This is evident in the dissemination done and in the attention placed on the METIS-II outcomes in standardization and regulatory bodies. The pre-standards consensus developed between the partners in the project has been critical to accelerate the standardization process and one of the reasons we will see the first 5G deployments in the next year. The results also have a high scientific relevance which is evident from the number of publications generated by the project.

Going forward there are some topics that will likely be remembered in the future. Although the standardization bodies work very hard to complete the first release of the 5G standard there are many things that will not be included in the first release. Here the results from METIS-II are of great interest and some of the innovations from METIS-II will likely end up in future releases. Another topic is the visualization platform that will be used for research and development in the future as well.

During the project lifetime 5G has moved from something that is done in the research labs to products that are almost ready to be deployed. As researchers we usually tend to underestimate the long-term impact of innovations and we believe that we will see large changes as connectivity is leveraged by other industries to transform the way they do business. We in the project believe the coming years will certainly be as exciting as the past two years.

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