Publishable Summary

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Project acronym:	MAMMOET
Project title:	Massive MIMO for Efficient Transmission
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Duration:	36 months
Programme:	FP7/2007-2013

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Chapter 1 Publishable Summary

Project name: **MAMMOET**
Grant Agreement: **619086**
Project website: http://www.mammoet-project.eu
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Start date: 1st January 2014
Duration: 36 months

Mission of MAMMOET *is to advance the development of Massive MIMO (MaMi), a new and highly promising trend in mobile access. MAMMOET shows the benefits – and overcomes the practical limitations – of MaMi and develops complete technological solutions leveraging on innovative low-cost and drastically more efficient and flexible hardware.*

The MAMMOET Project aims to:

- Advance the development of Massive MIMO (MaMi), a new and highly promising trend in mobile access.
- Show the benefits and overcome the practical limitations of MaMi.
- Develop complete technological solutions leveraging on innovative low-cost and drastically more efficient and flexible hardware.

Motivation:

The internet of the future will, to a large extend, rely on mobile networks. Mobile data grew by 70% in 2012 and is predicted to grow 13-fold in the next 5 years. This puts very high demands on the development of mobile access technology.

Multiple-antenna (MIMO) technology for wireless communications is becoming mature and incorporated into emerging wireless broadband standards like long-term evolution (LTE). Basically, the more antennas the transmitter and the receiver are equipped with, the higher the number of possible signal paths and the better the performance in terms of data rate and link reliability. The price to pay is increased complexity of the hardware (number of RF amplifier frontends) and the complexity and energy consumption of the signal processing at both ends. Therefore MAMMOET will investigate a complete technological solution leveraging on innovative low-cost and drastically more efficient and flexible hardware.

Objectives & Technical Approach:
MAMMOET aims to bring MaMi from an initial promising concept to a highly attractive technology for usage in future broadband mobile networks. In order to achieve its overall goal, the project has a number of important scientific and industrial objectives. These include fundamental, experimental and standardisation elements. The five main objectives are:

- **Objective 1: Elaborate system concepts and approaches**
  Provide an understanding of the statistical nature of the relevant channels and traffic and further additional channel measurements and validate already drawn conclusions in a broader range of scenarios. Investigation will focus on exploring which antenna configurations are most attractive and the analysis of possibilities and limitations.
- **Objective 2: Flexible and effective signal processing**
  Provide algorithms for distributed and scalable processing and hardware-friendly processing algorithms that allow to trade some of the extra degrees of freedom that MaMi provides to achieve constant envelope signals to transmit from each of the antenna elements.
- **Objective 3: Efficient implementation**
  Investigate which hardware components are suitable for building the large array of transmitters and how these can work together. Power-hungry hardware will be made more efficient when the specific properties of MaMi are taken into account.

- **Objective 4: Prove overall innovative concepts and enabling hardware (HW)**
  Create an attractive operational technology by bridging the gap between theoretical and conceptual MaMi.
- **Objective 5: Propose MAMMOET solutions to standardisation bodies**
  The standardisation focus will be on 3GPP (3rd Generation Partnership Project), with the goal of reporting to this standardisation body the potential of MaMi in future mobile standards. Some MAMMOET partners (TID, EAB, IFAT) will report back the latest outcomes relevant to project and provide contributions to the 3GPP standardisation process on behalf of the project findings.

Description of the work performed and results in the first project period

The MAMMOET project started on the 1st January 2014 and is set to run for 36 months. During the first project phase, corresponding to the first project year, the focus was placed on the analysis of on specifying relevant and realistic scenarios, outlining a system approach/architecture and analysing requirements. All work packages, apart from WP4 initiated work and produced altogether 5 Deliverables (including this first Periodic Report) throughout the first project year. At the beginning, major effort was put into the successful launch of the project. The major goal was to establish a sound basis for a good and fruitful cooperation of the project partners towards the research objectives. We managed to develop collaboration while creating a large number of publications and presentations documenting ideas that we can leverage and extend in subsequent years. This has been achieved by strong leadership and by optimizing the organisation and infrastructures. All relevant management components on contractual, financial, legal, technical, administrative and ethical topics were created and provided as well as catching upcoming obstacles well ahead of time. Furthermore, a public project website and the internal IT communication infrastructure were implemented. The progress achieved by all work packages within the first project year is in line with the initial plan and can be summarized as follows.

WP1 (System approach, scenarios and requirements)

The work in WP1 during the first year has set the scene for the project. The work on fundamental limits and scenarios for massive MIMO has been reported in D1.1. In parallel, channel measurements have been performed aiming to characterize massive MIMO channels.

The entire consortium has been involved in the definition of a minimum set of diverse and challenging 5G mobile broadband scenarios that are mostly relevant to massive MIMO. This has been a task of paramount importance, since the massive MIMO concept can only be understood and described properly if appropriate system scenarios are envisaged, with the goal of enabling actual capacity and energy improvements. Scenarios definitions amount on specifying the values of a set of parameters that are common to all scenarios and elaborating the main characteristics that are specific to each scenario. The selection of the prioritized scenarios has been driven by both technical and business related criteria. This ensures that MAMMOET results will focus on demonstrating substantial capacity and energy gains while maximizing the potential impact, targeting to increase the chances for adoption in commercial exploitation. Moreover, the baseline scenarios for performance comparisons have been identified. Moreover, the main operation of massive MIMO has been outlined focusing on physical layer technical functionality. The uplink and downlink signalling have been defined in a TDD-based transmission protocol and pilot-based channel estimation in the uplink has been described. The average spectral efficiencies achieved in such a system with a diverse selection of linear precoding/combining schemes have been derived.

In order to be able to properly evaluate massive MIMO solutions in other WPs, the power consumption has been modelled corresponding to the achievable throughput at different system levels (per user, cell, and area). Given the fundamental differences between the innovative transmitter architecture developed in MAMMOET and traditional (macro) BSs,

estimating their power consumption required a significant modelling effort, taking into account all the different components in order to assess the total system power consumption. This has been achieved and allowed to accurately define the energy efficiency metric.

The spectral efficiencies achieved by massive MIMO in a variety of different setups have been analysed mathematically and illustrated numerically. An finite-size and asymptotic analysis has first been performed first and has then been complemented by simulation results of optimized performance evaluations. The effect of the main scenario parameters and the impact of hardware impairments have been investigated. Moreover, scaling behaviours and practical trade-offs have been identified and derived. These results provide fundamental limits of the massive MIMO performance and the conclusions yield a valuable first insight that will be used to steer the MAMMOET research on algorithm development around the topics of channel estimation, pilot allocation, and phase-coherent precoding/combining.

Finally, channel measurements have been made for massive MIMO with special emphasis on the crowd scenario, which is considered as one of the most challenging scenario for today's cellular networks. Also, measurements for outdoor urban massive MIMO measurements have been characterized and work has started on an extension of the well-established COST 2100 channel model for massive MIMO scenarios.

WP2 (Efficient FE Solutions)

Keeping in view the upcoming deliverable D2.2, the main focus in WP2 up till now has been on developing a reconfigurable transmitter architecture targeting frequencies around 2.4Ghz. The transmitter for the first prototype test chip is a digital transmitter that allows an easy reconfiguration. Keeping in view the increasing speed of modern CMOS technologies, time-domain signal processing has been chosen instead of encoding information in voltage or current levels. After architecture design (Task 2.1), work has been started on Task 2.2, the actual implementation at circuit level for the first prototype. Also under Task 2.1, simulations have been performed on conventional I/Q, polar and digital baseband and RF – PWM concepts.

D2.1 has been completed and submitted on time during this reporting period. For Task 2.3, models have been created for channel non-reciprocity impairments in order to simulate their impact on performance of MaMi systems

WP3 (Baseband Solutions)

WP3 started its activities in April 2014 (M04) and has essentially progressed according to plan. Also the deliverable D3.1 has been submitted on time within the first project period. WP3 partners have performed investigations on many important topics related to massive MIMO baseband processing. The choice between single- and multi-carrier massive MIMO has been studied and initial conclusions are that there are no major differences in performance or implementation complexity.

Baseband algorithm performance vs. complexity trade-offs have been studied and optimized for massive MIMO specific scenarios. In particular, it has been identified to what extent the averaging of noise and uncorrelated distortions from hardware impairments over the different antennas allow for relaxed design constraints. The analysis shows that the quality constraints of each individual antenna branch can be greatly relaxed.

Linear and non-linear precoding techniques have been developed and studied, where the non-linear precoding is aimed at bringing lower power variations on individual antennas relaxing power amplifier requirements. Promising results have been obtained for non-linear precoders. The algorithmic complexity is in the same range as with linear precoding, but the implementation complexity has to be studied in more detail to draw final conclusions.

An overview of different hardware platforms for massive MIMO baseband processing has been compiled. In the early stages of the project, we will use highly flexible solutions, such as software-defined radios, while more specific implementations will be developed in later stages. Initial experiences from the massive MIMO testbed have shown that a critical part of realizing massive MIMO is related to reducing the amount of data that needs to be exchanged between different processing nodes when using distributed processing.

WP4 (Validation and proof-of-concept)

WP4 officially starts in the second year of the project. As a consequence, only a limited effort was spent on this WP in the first year, mainly anticipating on the future effort in order to speed up the validation results in year 2 and 3 and establishing connections with other WPs.

As overall validation work package, WP4 needs to be connected to WP1 where scenario definition takes place, in order to ensure the possibility to validate at least some of the selected scenarios in WP4. This was considered for both simulator-based and test-bed-based validation.

For the simulation-based validation (task 4.1), the high-level structure of the simulation framework was created and discussed within the consortium, in order to clarify both the usage of the simulator and the possibilities for contributions on specific components. A number of elements have been aligned within the consortium, such as the frame structure (uplink/downlink switches), channel models (time-varying options, integration of measurements) or inclusion of specific extensions (constant-envelope precoding, digital modulator, multi-antenna terminals). The actual development of the simulator has started for ideal scenarios.

For the test-bed-based validation (task 4.2), the assembly of the LuMaMi test-bed has started, including selection of components, mechanical design and assembly. This will enable to perform real-environment MaMi tests in time. Scenario parameters were harmonized between the physical test-bed and the simulation-based framework.

WP5 (Project management including Dissemination, Standardisation and Exploitation) consists of two parts.

The project management part was responsible for the effective organization of the project and covered all relevant management components. Some of the main achievements so far have been: the organization of meetings (e.g. Kick-Off and GA Meeting), the implementation of monthly EB Telcos, monitoring of work plan (Interim Management Reporting), supporting partners in everyday issues (handling day2day requests), etc.

For the Dissemination, Standardisation and Exploitation part, a robust IT infrastructure (web site, SVN repository including web access, mailing lists including mailing list archives) was established as early as M02 (D5.1; www.mammoet-project.eu) and regularly updated since. MAMMOET has also been advertised by web pages and press releases. Hardcopies of the MAMMOET project flyers have been distributed by partners at various events. The project is also visible on twitter. Two newsletters have been published and distributed. Dissemination activities are announced via http://www.mammoet-project.eu/news. In terms of dissemination management, to ease communication on publications, a mailing list for publication proposals has been established. A list of dissemination activities has been compiled and updated periodically. As Deliverable D5.5 “Updated plan and initial report on dissemination, standardisation and exploitation” [D5.5] is only due in M24, a first impression of all activities done within this first project year, is shown in section **Fehler! Verweisquelle konnte nicht gefunden werden.** ‘**Fehler! Verweisquelle konnte nicht gefunden werden.**’.

Expected final results and their potential impact and use

In general the prospect is that MAMMOET will significantly increase the overall understanding, state-of-the art and confidence level of Massive MIMO technology. The

technical progress is expected (and has started) on several inter-related aspects of the technology: exploring the theoretical limits, realizing efficient algorithms and hardware solutions for the digital baseband as well as the analogue/RF front-end, prototyping of components, and system-level validation including experiments in the very large testbed.

Given the outstanding capacity and energy efficiency potential of this technology, the progress towards convincing proof of concept can stimulate the take up by standards. Eventually, MAMMOET results will then end up in 5G networks and (hardware) systems.

Specifically, through a widespread dissemination of the project expertise and progress, both broad and in-depth knowledge of Massive MIMO technology will be raised. Indeed the quite exceptional dissemination results in view of the early project phase, illustrate the timeliness of the project and recognizes the expertise available in the consortium. Particular project results can also be used beyond the Massive MIMO focus, as for example the channel characterisation and the power efficient transmitters.

The MAMMOET Consortium

The academic and research institute partners in MAMMOET include pioneers in MaMi and groups with extensive experience in circuit design for wireless communications. The industrial partners are leaders in their fields and cover the entire chain from component manufacturing to systems development and service provisioning. This means the MAMMOET consortium is well-positioned to achieve its objectives by bringing together a European team with 8 project partners from 4 different countries.

MAMMOET project public website

The official MAMMOET project website is available at the following link: http://www.mammoet-project.eu.

MAMMOET Disclaimer

All public information will be marked with the following MAMMOET project disclaimer: *"The MAMMOET project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement number ICT-619086."*