

PROJECT FINAL REPORT

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Project acronym: EXALTED

Project title: Expanding LTE for Devices

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Project website Error! Bookmark not defined. **address:** <http://www.ict-exalted.eu>

¹ Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

EXECUTIVE SUMMARY

During the past thirty months the EXALTED project has worked on M2M communications and delivered a rich set of solutions addressing various aspects of a M2M system. The key objective of the project is to establish scalable network architecture over 3GPP/LTE infrastructure and provide secure, energy-efficient and cost effective communication solutions for low-end devices.

The project provided a scalable system architecture for M2M communications over 3GPP/LTE infrastructure as a reference model, considering the features of 3GPP MTC and ETSI M2M architectures. Technical work packages addressed different parts of the architecture and proposed novel solutions (which are discussed in the following sections) for enhancing the functionalities and feature of the architecture. The proposed technical solutions have been extensively studied using analytical models and/or simulations. Proof of concept test platforms have also been developed and evaluations have been performed showing some of the key benefits of EXALTED solutions.

The technical works of the project resulted in several journal and conference publications and contributions to standards. Thanks to both a very detailed **Standardization** plan, and commitment from leading industry partners, the EXALTED project has demonstrated its influence and impact towards **SDOs** (3GPP, ETSI) by submitting and presenting a total of **48 contributions**.

Regarding **Dissemination**, the consortium presented **53 papers** with results of the EXALTED research at a number of prestigious international **conferences and workshops**, such as IEEE WCNC.

The EXALTED project has also presented **11** articles in an international journal and has attended several events where the project goals and scientific knowledge have been presented.

Last but not least, **14 (fourteen)** patent applications have been filed partners in relation to technical developments in EXALTED.

Three workshops were organized in major conferences, namely IEEE Globecom 2011, IEEE Globecom 2012, and IEEE WCNC 2012 (jointly with external partners). The workshops included technical sessions, keynote speeches, and panels, and were very fruitful in terms of discussions and new ideas.

A **Summer School** has been currently being organized in cooperation with other european projects (LOLA, SmartSantander, ...).

Finally, the overall outcomes and achievements of the EXALTED project, demonstrate true interest, commitment and cooperation from partners, with a visibility, influence and impact among the whole ecosystem thanks to active contributions, and lively participations to SDOs, industry groups that are shaping the future of the related technologies.

1. EXALTED Concepts

The aim of EXALTED is to lay out the foundations of a new scalable network architecture supporting most challenging requirements for future wireless communication systems and providing secure, energy-efficient and cost-effective machine-to-machine (M2M) communications suitable for low end devices interacting over 3GPP Long Term Evolution (LTE) infrastructure.

Duration: Sept. 2010 – Feb. 2013 (30 Months)

Consortium: 14 partners

- Countries: 6
- Industrial (Operator): Vodafone Group Services Limited (VGSL), Telekom Srbija (TKS)
- Industrial (Manufacturer): Sagemcom (SC), Sierra Wireless (ex-Sagemcom Energy & Telecom (SCET)), Gemalto (GTO), Alcatel-Lucent Deutschland (ALUD), Ericsson d.o.o Srbija (EYU)
- SME: TST Systemas SA (TST), Vidavo SA (VID)
- Research Centres: Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)
- Higher Education: University of Surrey (UNIS), University of Dresden (TUD Vodafone Chair), University of Piraeus Research Center (UPRC)



Total Budget: 10.3 M€

Maximum EC funding: 7 M€

Resources: 982 PM

Public Deliverables: 25

Website: <http://www.ict-exalted.eu/>

The EXALTED Consortium is also supported by an Advisory Board with representatives of standardization body (ETSI), academics (University of Bremen, University of Austin), industry forum (NG Connect), market research firm (IDATE).

2. Project Objectives and Challenges

EXALTED addresses important challenges posed to M2M systems and is proposing solutions to face the ever-growing demand for diverse M2M applications with modest communication needs but with strong energy limitations and network reliability requirements.

Network scalability and complexity issues resulting of the huge number of interacting autonomous devices are also addressed.

M2M communications are often characterized by a need for both proximity and global communications. Hence, to facilitate application developments, a unified framework for M2M systems and services integrated with the rest of the all-IP networks for global coverage is being defined.

Other important challenges for economic viability of the EXALTED solutions are: a cellular M2M market characterized by low revenue per device or service but with low churn, and interoperability and standardization needs.

Then, EXALTED expects the following outcomes:

- A new **scalable end-to-end** network architecture **over 3GPP LTE infrastructure** aiming towards an *all-IP* networking system for efficient and cost-effective M2M communications
- **Cost, spectrum, and energy-efficiency** of radio access technology and of mechanisms for M2M applications co-existing with high capacity LTE networks
- **Power and energy-efficient** M2M devices gateways supporting **low-cost autonomous operations** for months or years.
- **Low-cost, automated, security and provisioning solutions** for M2M communication over LTE
- Standardization and dissemination of project results

To sum up, the EXALTED vision, as illustrated in Figure 1 below, is that of “a new scalable network architecture supporting the most challenging requirements for the future wireless communication systems and providing secure, energy-efficient and cost effective Machine-to-Machine (M2M) communications suitable for low end devices” toward the future Internet of Things.

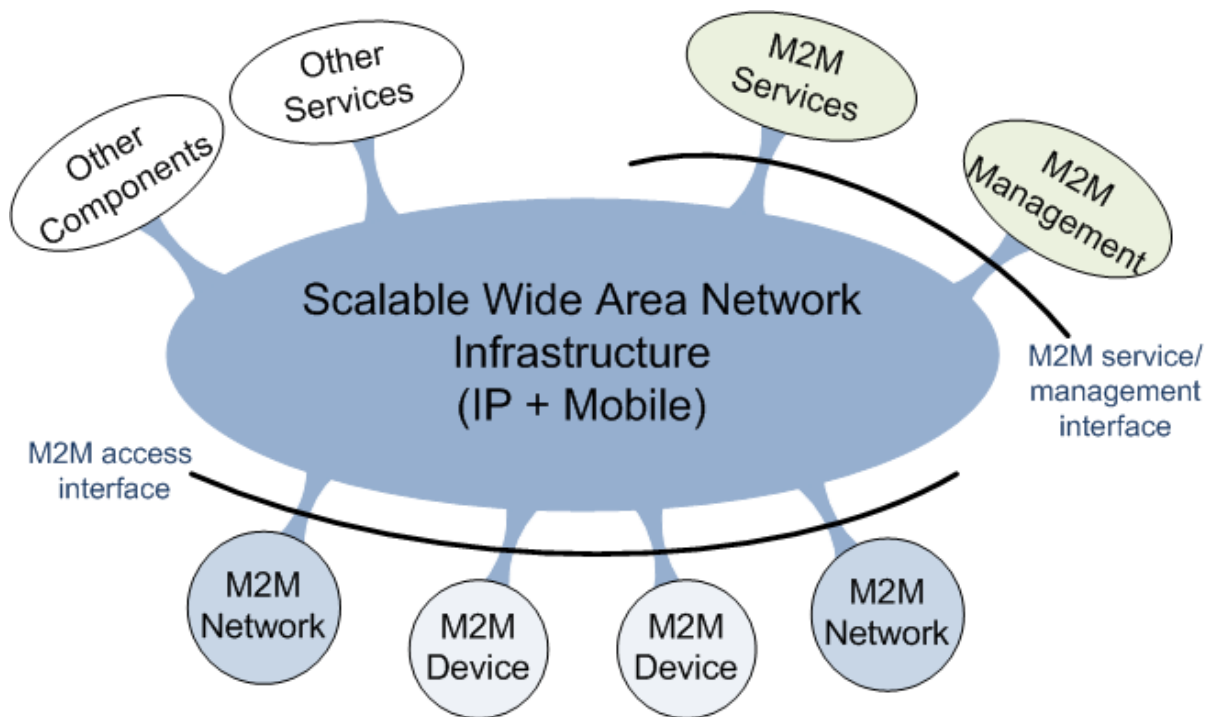


Figure 1: EXALTED vision

3. Work Achievements

During the past thirty months the EXALTED project has worked on M2M communications and delivered a rich set of solutions addressing various aspects of a M2M system. The key objective of the project is to establish scalable network architecture over 3GPP/LTE infrastructure and provide secure, energy-efficient and cost effective communication solutions for low-end devices. The technical works of the project resulted several journal and conference publications and contributions to standards.

The project provided a scalable system architecture for M2M communications over 3GPP/LTE infrastructure as a reference model, considering the features of 3GPP MTC and ETSI M2M architectures. Technical work packages addressed different parts of the architecture and proposed novel solutions (which are discussed in the following sections) for enhancing the functionalities and feature of the architecture. The proposed technical solutions have been extensively studied using analytical models and/or simulations. Proof of concept test platforms have also been developed and evaluations have been performed showing some of the key benefits of EXALTED solutions.

Since the main focus of EXALTED is future M2M network(s) based on 3GPP LTE network framework, the EXALTED system architecture, a novel LTE-M system has been proposed and a complete set of protocol stack is specified. The main components, including novel frame structure, PHY/MAC layer techniques, RRC layer solutions, and multicast/broadcast mechanisms have been developed within the project. A complete evaluation of LTE-M system concepts under different scenarios has also been performed. The novel solutions resulted from this work lead to several contributions to 3GPP.

E2E M2M communications require efficient and reliable operations of devices directly or indirectly connected to the LTE/LTE-M access, network. The support of capillary networks (i.e. the networks with indirectly connected devices) brings more added value to the EXALTED system architecture for example in terms of flexibility (support of different access technologies, remote device management, etc.) scalability (number of devices supported, etc.), and extended coverage. Different device categories have been defined in EXALTED, and the devices with no LTE-M access interface are put in the capillary networks behind M2M gateway(s). For efficient networking of such devices various protocols and algorithms including cooperative MAC techniques and IP networking techniques with novel address translation mechanisms for constrained devices have been proposed. Further, novel lightweight device management protocols and framework, data aggregation techniques, and network monitoring framework for constrained devices have also proposed. An integrated system incorporating the proposed techniques has also been defined, with evaluation results under different scenarios. Contributions have been made to IETF based on novel IP networking solution for constrained devices.

Providing low cost automated authentication and device provisioning solutions as well as security of the provisioning of M2M communications in LTE-M and inside capillary networks is another key objective of the project. Towards this objective, a new type of secure element, called embedded secure element has been defined with several of its variants to support different scenarios studied by the project. This embedded element proposal has been further supported by novel remote provisioning techniques identified within the project. How to delegate the authentication with the support of M2M gateway has also been investigated. The security requirements for broad/multicast communication and P2P relaying have been detailed, and initial specifications for securing such communications have been completed. The final evaluations on the proposed solutions have been performed and recommendations are made for the communication scenarios seen in the EXALTED system. Based on the security solutions, several contributions have been made to ETSI.

Improving the energy efficiency of devices is another key objective of the project. Several techniques, including optimized sleep wake-up cycles for LTE-M devices, novel MAC procedures and Linux kernel improvement techniques for reducing the power consumption have been proposed to improve the energy efficiency of M2M devices. A self-diagnostic module architecture together with novel features has been proposed to improve the reliability of the devices. In addition, a demonstrator prototyping has been made incorporating an energy-efficient, reliable and secure M2M module for demonstrating the security features of M2M devices and pairing mechanisms.

EXALTED has prototyped couple of test platforms for demonstrating some of the key features of the technical solutions proposed by the project partners. Integration of technical solution into the test platforms has been completed. Demonstrations of selected test platforms have been performed in several occasions such as Future Networks and Mobile Summit 2012. The validation of selected EXALTED system concepts on the test demonstrator platforms has been completed.

3.1 WP2

WP2 provided reference use cases, deployment scenarios and business models for evolved M2M communications as well as the technical requirements for LTE-M, heterogeneous M2M networking, security functionalities, and device management. Moreover, WP2 gathered, coordinated and aligned the innovations resulting from the work in all the technical work-packages and established the unified EXALTED system concept. The performance of the EXALTED system was evaluated after having defined a common evaluation methodology and scenarios. In the following the WP2 achievements are assessed against the corresponding objectives.

3.1.1 Identifications of use case of interest and definition of M2M deployment scenarios

An extensive analysis of the current and future M2M market was performed, along with a thorough presentation of the specification groups' and other stakeholders' activities and advances. Additionally, several potential use cases and M2M applications were detailed. Based on the market analysis, three main scenarios were investigated, identifying their requirements, challenges and their possible deployment phases:

- Intelligent Transport System (ITS) – communication of vehicles and transport infrastructure with ITS application servers, which controls parameters such as transportation time, traffic collision avoidance, on-board safety, fuel consumption, and many others.
- Smart Metering and Monitoring (SMM) – very applicable use case of industrial, environmental, energy, and other types of monitoring.
- E-healthcare – a relationship between a healthcare organization and a patient, established through the M2M communication.

These scenarios served as the common starting platform for further and detailed investigations of the technical assumptions of the EXALTED vision. Moreover, their investigation provided answers to critical issues, such as the optimal deployment strategy, which will lead to the desired system architecture and specifications. Additionally, the regulatory initiatives related to the M2M technologies and applications were analyzed, along with some technical aspects of important standardization bodies and consortium.

3.1.2 Investigation of the impact of the use cases and deployment scenarios on the underlying M2M business models

The commercial impact of the EXALTED project was investigated, based on the identified use cases. For each application area the relevant market characteristics were analyzed:

Intelligent Transport Systems (ITS): With a total market size estimated at 1 trillion USD and the large scale telematics programs mainly triggered by European and International Regulation Authorities seeking a large piece of it amplified by the renewed interest of the car manufacturers to provide added value telematics services in order to promote their brand image is a valid candidate for profitable M2M deployment

Smart Metering and Monitoring (SMM): Some sectors have increasing concerns which are driving the need for more sophisticated sensing approaches: a good example is environmental monitoring/flood monitoring, where flexible monitoring with good density of coverage is typically needed. However the business model and demands are not evident to justify thousands of nodes being deployed in extensive monitoring systems. Nonetheless there is increasing awareness and demand for greater use of sensors to, for example, improve processes, safety, environmental monitoring, to reduce operational costs or meet changing regulatory or policy requirements.

eHealth: The European eHealth market is projected to reach €15.619 million by 2012, with a compounded annual growth rate of 2.9%. Remote monitoring of patient's vital signs through the use of devices customised by health care providers to target the specific needs of the individual applies best to the M2M world. The European remote patient monitoring market where the estimated revenues for 2009 were approximately €230 million while the estimation for 2015 is for double this amount reaching €450 million is a suitable market for M2M deployment as aging population and high prevalence of chronic diseases is the most important market driver.

EXALTED and LTE-M in particular could meet the needs of stakeholders. Faster growth of M2M applications could be achieved through the adoption of the improved characteristics of the EXALTED system, including node and cellular network modifications, which could lower the overall system costs and increase the spectrum utilization efficiency.

3.1.3 Specification of technical requirements

The technical system requirements for the EXALTED system were identified based on the analysis of the adopted use cases and scenarios. The system requirements were given in a consolidated manner, in order to ensure an effective end-to-end (E2E) system description, with references to particular scenarios that they can be applied to. The requirements were grouped into the following categories:

- Functional requirements describe specific features of the EXALTED system that are needed to enable the envisaged use cases.
- Service requirements related to M2M services such as prioritization, session continuity, coexistence of multiple service providers on one single device, provisioning, remote change of subscription, delegation of functionality, and security aspects.
- Network requirements related to network infrastructure needed for establishing E2E M2M communication.
- Non-functional requirements are used to outline the required quality characteristics of a system.
- Device requirements that are closely related with the different devices in the EXALTED system are described.

These technical requirements were extracted based on the standardization bodies' point of view through the EXALTED prism and served as the baseline for the development of EXALTED system framework and components.

3.1.4 System concept description

Following a thorough investigation of the most emerging M2M applications and use cases, the most critical requirements (e.g. functional requirements, network requirements, and service requirements), were identified towards the development of the necessary corresponding algorithms, procedures and technologies. The system architecture provides a coherent framework, ensuring that all technical innovations are aligned towards a unified system concept, able to achieve the project's objectives. Through an iterative process between the technical innovations and the system architecture, and after cycles of refinements and interactions between contributors covering different parts of the EXALTED system, the final architecture provides a consolidated view of the EXALTED concept.

The EXALTED system is founded on two existing proposals that are considered as baseline architectures, namely the 3rd Generation Partnership Project (3GPP) Machine Type Communications (MTC) and European Telecommunications Standards Institute (ETSI) M2M, aiming to the necessary enhancements at the Network Domain (ND) and the Device and Gateway Domain (DD), in order to leverage on these standardization efforts and complement them with new sets of features needed to provide cost, energy, and spectrally efficient connectivity to a large number of devices. The EXALTED architecture consists of components and interfaces. Components can be either physical entities, e.g. devices, or the logical combination of functions, e.g. Evolved Packet Core (EPC) and M2M server. All the components are characterized by their functionality, which can be either mandatory or optional. Algorithms realizing these functions are considered to be exchangeable and not part of the architecture.

The working assumption for the EXALTED architecture was that it consists of various *components* characterized by their *functionalities*. A component can either be a physical entity, e.g. a M2M device, or a logical element summarizing certain functions that are in reality distributed at different locations, e.g. the Evolved Packet Core (EPC) and *interfaces* between these components. The functionality of a component can be realized by *algorithms*, and interfaces can be implemented with *protocols*. Candidate algorithms and

protocols are being developed in the WP3-WP6 and are part of the *EXALTED system concept*. They are exchangeable without impact on the architecture design itself.

3.1.5 Evaluation methodology definition

Within EXALTED a common evaluation methodology was followed with common assumptions, which served two major goals. The first one was the performance comparability of the various innovations within the EXALTED system and the second one was to provide useful evaluation guidelines for the evaluation of M2M solutions, underlining important aspects, such as topologies, traffic models and simulation parameters. Based on these common evaluation assumptions, the performance of the EXALTED system was assessed against the main objectives through a set of corresponding evaluation scenarios:

- supporting a large number of LTE-M devices with heterogeneous requirements and capabilities,
- low complexity and energy efficient M2M communications for LTE-M-based systems,
- end-to-end (E2E) connectivity (Heterogeneity and Interoperability),
- traffic aggregation,
- device management and
- E2E Security.

The objectives were evaluated against the Key Performance Indicators (KPIs) that are directly related with the objectives of the EXALTED system. Among others, the most important KPIs include: the relative increase of the number of M2M devices that can be supported by LTE-M, compared to LTE, the spectral efficiency, the battery power savings, the network lifetime, the number of addresses mapped to M2M devices, the reliability of device connectivity, the coverage extension, the mobility management efficiency, the throughput and the payload reduction.

The evaluation of the EXALTED system proved that significant benefits can be acquired.

3.2 WP3

The aim of the work package was the specification of LTE-M, a cellular mobile radio system co-existing with LTE in the same frequency band and facilitating cost-, spectrum-, and energy efficient M2M communications.

3.2.1 Overall Progress of WP3

WP3 consists of the four tasks T3.1 (PHY layer), T3.2 (MAC scheduling protocol for M2M communications), T3.3 (Dynamic resource management), and T3.4 (Broadcast & Multicast capability). It turned out that these tasks cannot be treated independently, but that the diverse challenges and technical requirements demand substantial cross-task activities to design a coherent system. Therefore the work was split up into objectives rather than into tasks. The following objectives have been addressed.

- Co-existence with LTE
- Simultaneous support of a big number of machine devices and spectrum efficiency
- Provision of wide area coverage
- Energy savings to enable a long battery lifetime
- Cost efficiency

It is claimed that all of these objectives led to reasonable results in accordance with the initial project proposal. A detailed performance analysis can be found in the final project report D3.4. In order to achieve this, the work package was deeply involved in the EXALTED architecture discussion (WP2). As LTE-M is the enabling technology for E2E connectivity, also a close cooperation with WP4 took place throughout the project duration. Key algorithms have been transferred to WP7 for their implementation in one of the testbeds. Furthermore, over thirty publications and standards contributions underline the significant impact of WP3 activities in the research community.

WP3 produced four public deliverables:

- D3.1 (First report on LTE-M algorithms and procedures), version 2.0 released in Jan. 2012, includes a state of the art analysis and introduces the toolbox approach concerning candidate algorithms for LTE-M **Error! Reference source not found..**
- D3.2 (Study of commonalities and synergies between LTE-M and the heterogeneous network), released in Aug. 2011, is a joint effort with WP4 and gives an outline about the relationship between LTE-M and the system components installed around **Error! Reference source not found..**
- D3.3 (Final report on LTE-M algorithms and procedures), released in July 2012, is the continuation of D3.1 and defines for the first time the overall LTE-M system. Moreover, the specification of the toolbox algorithms is presented **Error! Reference source not found..**
- D3.4 (LTE-M performance evaluation), released in Jan. 2013, includes the full specification of LTE-M and the expected performance per objective **Error! Reference source not found..**

In the following, the most important achievements are briefly summarised.

3.2.2 LTE-M System

LTE-M fully complies with the EXALTED architecture and is one key part of the overall EXALTED system concept. User plane and control plane of the radio protocol architecture are very much based on LTE. The only substantial modification is the option that the eNodeB may serve as IP client for the LTE-M device and map the IP address to a shorter local address. However, LTE-M utilises its own logical-, transport-, and physical channels. Within the existing LTE frame structure, so-called Multicast-Broadcast Single Frequency Network (MBSFN) subframes are available for LTE-M, and the different physical channels are mapped in form of an LTE-M super-frame to these radio resources, a solution that is fully compatible to previous LTE releases and still opens the opportunity to implement specific algorithms and protocols tailored for the needs of M2M communications. Optimisations of the random access procedure and of the Hybrid Automatic Repeat Request (HARQ) functionality are the essential modifications in the MAC layer. Radio Resource Control (RRC) and Packet Data Convergence Protocol (PDCP) were adapted as well according to the specific needs of a system suitable for a multitude of short messages from devices with diverse capabilities and requirements. Key enabler is here the registration of information about the devices and their context in the network and the selection of the right mechanisms. As an example, sensors installed at a fixed position don't need any form of mobility management. The actual intelligence of LTE-M is to recognise the situation and to activate or deactivate a set of simple features.

3.2.3 Co-existence with LTE

Two project objectives are reflected, namely that the proposed solutions have to be supported by existing eNodeB hardware platforms (O3.1) and that backward compatibility to LTE Release 8 is maintained (O3.7). The abovementioned LTE-M system design as a whole already underlines these requirements, e.g. through the separation of radio resources for LTE and LTE-M devices. But also some individual solutions were explicitly specified to support this co-existence. Registering information about terminals is the key enabler. Thereby, it is possible for the network to distinguish between LTE and LTE-M terminals. This is necessary to exploit the

performance potential of innovative scheduling techniques. Other solutions protect the network against sudden overload situations, simply allow re-using already existing hardware components, or maintain the performance of LTE UEs in the presence of LTE-M traffic. The following table summarises the proposed solutions, indicates how they can be applied beneficially, and points out possible interactions with other EXALTED solutions.

Solution	Expected performance	Recommended usage	Interactions with other EXALTED solutions
Registering information about terminals	Co-existence achieved with respect to backward compatibility	General usage in LTE-M systems	Enabler of other solutions that exploit this information, e.g. scheduling, optimisation of paging.
Slotted access	Co-existence achieved with respect to avoidance of network overload situations	Event-driven applications with a big number of devices	Combination with ‘Random Access with Collision Recovery’ is recommended.
HARQ for LTE-M	Co-existence achieved with respect to re-use of existing hardware components	Generally applicable, but tailored for applications with short messages	It is required to adapt the LTE-M rate matching algorithm according to the proposed HARQ scheme.
Innovative scheduling techniques	Co-existence achieved with respect to maintaining the performance of LTE UEs in the presence of LTE-M devices	Generally applicable, but particularly beneficial in heterogeneous environments with mixed applications and QoS classes.	It can be used in all cases, where ‘Semi-persistent scheduling’ cannot be applied. Both approaches complement each other.
GFDM	Co-existence achieved with respect to maintaining the performance of LTE UEs in the presence of LTE-M devices	Generally applicable, but tailored for applications with short messages	GFDM replaces SC-FDMA in LTE-M uplink. A combination with CDMA-overlay is possible.

3.2.4 Simultaneous support of a big number of machine devices and spectrum efficiency

One of the major objectives in EXALTED is the simultaneous support of a big number of LTE-M devices. As the amount of the overall available radio resources for LTE-M is fixed through the LTE frame structure and the LTE-M super-frame principle, the challenge is to transmit the same information by using fewer resources. This can be achieved either by minimising the size of control and feedback messages (O3.2), or by optimising the resource utilisation by traffic aggregation or novel signal formats (O3.4). Again the diversity of device capabilities and requirements plays an important role (O3.5). Signalling reduction can be realised e.g. by semi-persistent scheduling, and examples for spectrum efficient techniques on the payload are GFDM and the

HARQ scheme. An optimisation of the random access procedure and specialised scheduling techniques showed additional improvements. The following table summarises the proposed solutions. Benefits between some ten and some hundred percent were observed. All in all, with a suitable combination of the proposed methods the number of supported devices can be increased by one order of magnitude.

Solution	Expected performance	Recommended usage	Interactions with other EXALTED solutions
Random access with collision recovery	80% throughput improvement on PMRACH	Applications with a huge number of devices, but rare transmissions	Combination with ‘Slotted access’ is recommended.
HARQ for LTE-M	Up to 30% more LTE-M devices	Generally applicable, but tailored for all applications with short messages	It is required to adapt the LTE-M rate matching algorithm according to the proposed HARQ scheme.
Semi-persistent scheduling	500% - 1000% more LTE-M devices	Applications with frequent time-driven transmissions	This solution complements the proposed innovative scheduling concepts.
Slotted access	900% more LTE-M devices	Event-driven applications with a huge number of devices	Combination with ‘Random Access with Collision Recovery’ is recommended.
AGTI scheduler	Up to 1000% more LTE-M devices	Beneficial if applications with different delay constraints are mixed	It can be used in all cases, where ‘Semi-persistent scheduling’ cannot be applied. Alternatives are ‘QoS based scheduler’ and ‘Scheduling algorithm for heterogeneous traffics’.
QoS based scheduler	Up to 1000% more LTE-M devices	Beneficial if applications with different delay constraints are mixed	It can be used in all cases, where ‘Semi-persistent scheduling’ cannot be applied. Alternatives are ‘AGTI scheduler’ and ‘Scheduling algorithm for heterogeneous traffics’.
GFDM	Up to 35% more LTE-M devices	Generally applicable, but tailored for applications with short messages	GFDM replaces SC-FDMA in LTE-M uplink. A combination with CDMA-overlay is possible.
Scheduling algorithm for heterogeneous traffics	Up to 1000% improvement based on definition of	Beneficial if different LTE and LTE-M traffic types are mixed	It can be used in all cases, where ‘Semi-persistent scheduling’ cannot be applied. Alternatives are ‘AGTI scheduler’ and ‘QoS

	satisfied users		based scheduler’.
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3.2.5 Provision of wide area coverage

This is another important aspect of the EXALTED objective to support devices with diverse capabilities and requirements in one system (O3.5). Cost- and complexity reduction are sublime objectives. However, they cause some drawbacks. The main problem is the degradation of the link budget, particularly in the uplink. At the end, this leads to insufficient coverage of LTE-M devices because the cellular layout is dimensioned according to the LTE specification. Two solutions were developed that ensure wide area coverage also for LTE-M. CDMA-overlay in the uplink exploits the simple principle of a spreading gain. For the downlink a collaborative broadcast architecture is proposed that achieves a very high level of coverage. The following table summarises the proposed solutions.

Solution	Expected performance	Recommended usage	Interactions with other EXALTED solutions
CDMA-overlay	97% coverage in the considered scenario	LTE-M uplink for applications with power-limited devices if the radio channel quality is bad	It can be combined with GFDM, but also with SC-FDMA or OFDMA.
Collaborative broadcast architecture	100% broadcast coverage	One message is addressed to multiple devices in the LTE-M downlink	Combination with E2E solutions for capillary networks studied in WP4.

3.2.6 Energy savings to enable a long battery lifetime

Besides spectrum efficiency, energy efficiency is the second big challenge in EXALTED. In other words, the lifetime of the battery shall be extended from a couple of days to the duration of years. In order to be able to analyse this complex problem, at first the sources of energy consumption in a conventional LTE UE were analysed, and a relative breakdown was derived. Thereby it is distinguished if the device is in ACTIVE mode or in IDLE mode. In a subsequent step, several solutions were studied with respect to the specific source of energy consumption that they try to reduce or to avoid. Apart from the obvious project objective of energy minimisation in the device (O3.6), also the optimisation of paging and polling of devices (O3.3) was handled. The analysed solutions range from RRC protocol optimisation till unconventional techniques like energy harvesting. The following table summarises the proposed solutions. The final conclusion is that it is possible, depending on the characteristics of the application, to achieve battery lifetimes in the range of one year.

Solution	Expected performance	Recommended usage	Interactions with other EXALTED solutions
Energy Harvesting	Energy reduction up to 6% for the evaluated case	Isolated power limited devices	No interaction with other solutions known.

Random access with collision recovery	Energy reduction up to 11% for the evaluated case	Applications with a huge number of devices, but rare transmissions	Combination with ‘Slotted access’ is recommended.
Collaborative broadcast architecture	Must be considered together with capillary networks.	One message is addressed to multiple devices in the LTE-M downlink	Combination with E2E solutions for capillary networks studied in work package 4.
Directional antennas	Energy reduction 1%	Beneficial in scenarios with limited feedback capacity	It is useful to combine the solutions with the methods aiming at the support of a big number of users.
LDPC codes for incremental redundancy multicast	Average energy reduction 12.5%	To be used in the LTE-M downlink if the same message shall be delivered to a big number of devices	No interaction with other solutions known. It is exclusively applied in the PMDMCH.
Low complexity MIMO	Average energy reduction 4.75 %	All LTE-M uplink scenarios with sufficient coverage	No interaction with other solutions known.
Registering information about terminals	No gain as stand-alone solution	General usage in LTE-M systems	Enabler of other solutions that exploit this information, e.g. scheduling, optimisation of paging.
Adaptive paging	Reduction of paging messages by factor 20-50 in average	All applications with fixed devices	Enabled by ‘Registering information about terminals’.
Monitoring paging channel and mobility support	Up to 30% energy reduction in IDLE mode	All application with long periods in IDLE mode	Enabled by ‘Registering information about terminals’.

3.2.7 Cost efficiency

Similar as for energy consumption, the assessment of cost reduction is based on a breakdown of the contributions from the different hardware components. For this, EXALTED adopted the work of 3GPP, summarised in the technical report 36.888 [5], which already provides a broad set of means for cost reduction for M2M devices. The added value from EXALTED, aiming at the objective to minimise the device complexity (O3.2) is basically the proposed MIMO scheme. The expected performance is given in the following table.

Solution	Expected performance	Recommended usage	Interactions with other EXALTED solutions
Low complex MIMO	9% cost reduction	All LTE-M uplink scenarios with sufficient coverage	No interaction with other solutions known.

3.2.8 Summary of Technical Achievements

- Outline system design of LTE-M that fulfils demand for co-existence with LTE and that is compatible with existing network infrastructure
- Provision of means to extend the number of supported devices by factor 10.
- Provision of means to achieve a device battery lifetime in the range of one year.
- Provision of means to maintain wide area coverage in spite of device and protocol simplifications
- Additional device cost reduction of 10% on top of means proposed by 3GPP
- Enabling E2E connectivity based on IPv6 for devices in capillary networks

3.3 WP4

WP4 aims to establish a complete end-to-end (E2E) architecture for an M2M capillary network based of LTE-M. The work package released three interim reports (IR4.1...IR4.3), and five deliverables (D4.1... D4.5). In addition, the work package produced one supplementary public deliverable in conjunction with WP3 (D3.2).

Overall, WP4 worked along the following layers:

- PHY: signal compression techniques for sensors around fusion centers, beamforming and diversity for aggregating data, clustering mechanisms.
- MAC: mobility models, dynamic encoding schemes for media access , energy-efficiency
- Networking: address translation schemes for sensor devices and vehicular networks, as well as address and prefix auto-configuration protocols also for vehicular networks.
- Application: payload optimization and device management and short messaging for constrained devices, network monitoring for sensor-class devices and machine-type entities.

An end-to-end system architecture for EXALTED was produced in WP4. The definition of nodes, functionalities and communication modes within it were defined.

3.3.1 Common View of WP4 Achievements

This section classifies all mechanisms and protocols proposed in WP4 with respect to the main objectives identified in DoW document.

It is possible that one solution is duplicated in more than one objective, as it may cover different innovations.

3.3.2 O4.1 Maintaining connection/transmission integrity across aggregation points through heterogeneous connections

- S4.1.1. Single hop cooperative MAC protocol for high number of devices (D4.1)
- S4.1.2. Heterogeneous connectivity and address translation (D4.1 & D4.2)

- S4.1.3. Mobility model estimator (D4.1)
- S4.1.4. Distributed Cluster-based communications (D4.4)

3.3.3 O4.2 Efficient and consistent IPv6 Packet mapping throughout and across the connections to ensure lowest IP overhead possible

- S4.2.1. Payload Reduction (D4.1)
- S4.2.2. V2V2I communication using VIN addressing (D4.2)
- S4.2.3. SoTA on 6LowPAN mobility (D4.2)

3.3.4 O4.3 Define device management architecture that ensures consistent node resource exposure and warrants reliable and uniform addressability and security

- S4.3.1. Device management architecture (D4.3)
- S4.3.2. ELFOMA protocol (D4.3)
- S4.3.3. CoAP-DM over SMS and UDP (D4.3)
- S4.3.4. ASN.1 encoding (D4.3)

3.3.5 O4.4 Traffic aggregation point architectures to support reduced traffic load

- S4.4.1. Multi-hop MAC protocol for increasing energy efficiency (D4.1)
- S4.4.2. DISC protocol (D4.4)
- S4.4.3. CHANGE protocol (D4.4)
- S4.4.4. Data Compression (D4.4)
- S4.4.5. Multi-point communications (D4.4)
- S4.4.6. Decentralized Source coding (D4.4)

3.3.6 O4.5 Design an IP based E2E networking system for M2M communications (Machine: unattended device running for extended periods of time).

- S4.5.1. IP address assignment (D4.1)
- S4.5.2. V2V2I communication using VIN addressing (D4.2)
- S4.5.3. Heterogeneous connectivity and address translation (D4.1 & D4.2)

3.3.7 O4.6 Device / node monitoring mechanism to ensure that a response-to-demand datum is authentic reliable and secure

- S4.6.1. Network Monitoring architecture (D4.5)
- S4.6.2. Light-weight monitoring mechanism (D4.5)

3.3.8 WP4 Complete protocol stack

This section provides the big picture about where and how protocols proposed in WP4 fit together.

They are classified with respect to the layer that they cover. Layers taken into account for this purpose are physical layer (PHY), link layer (MAC), network layer (IP) and application layer (APP).

In addition, compatibilities and incompatibilities are identified. The assumption is that all protocols are independent to upper and lower layers; for instance, an EXALTED MAC protocol can use any of the proposed (or already existing) PHY or IP protocols.

Within the same layer, protocols that can coexist with any other solution in the same layer are pictured in green. On the other hand, if a protocol is exclusive and avoids by definition the use of alternative techniques at the same layer, it is pictured in red.

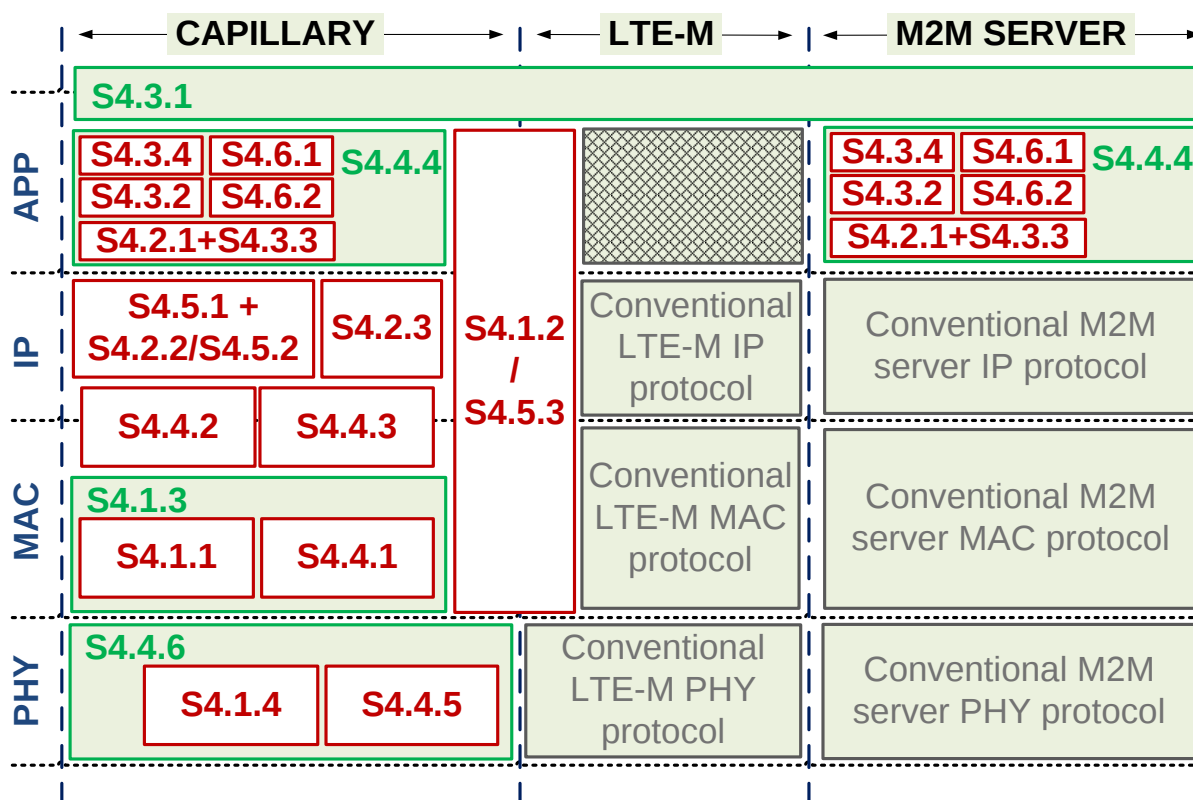


Figure 3.1. Protocol Stack.

The notation “conventional” means that any typical protocol for that layer and in that particular equipment/network can be used, as it is transparent for the defined Stack.

In the following description we show how each solution mentioned above was defined during the project timeframe.

3.3.9 Task 4.1

Task 4.1 investigated the aspects of maintaining continuous packet data transport level continuity between heterogeneous physical layer network links in an end-to-end M2M scenario over LTE. The goal is to minimize the required overhead while satisfying packet data connectivity reliability, energy consumption and throughput/delay constraints. In order to achieve Task 4.1 objectives, the work during the first year lied in three main aspects:

- Data packet continuity
- New MAC protocols for capillary networks optimized for M2M particularities
- Single user and group mobility.

After reviewing the diverse literature existing in each field aforementioned, some preliminary results have been achieved and presented in the internal meetings carried out by WP4.

A first demonstrator has been performed; it aimed at integrating both ZigBee and IP networks. It is composed by a gateway (IP enable) and a M2M device (non IP) connected through the ZigBee interface. After studying the different solutions for integrating both worlds, the most effective scheme for M2M characteristics, based on a web server at the gateway, has been implemented. The presented platform is capable to send commands or access to the information of the M2M device from any point connected to an IP network.

Two complementary approaches were performed at MAC level. The first one is **Cooperative ARQ**, a MAC protocol considering energy efficiency as primary focus due to the characteristics of M2M communications. The work done includes MATLAB simulations that demonstrate the improvement in energy efficiency. As result of this work a paper has been published in NEWCOM 2011 conference. A theoretical framework for integrating shadowing effects in MAC design is also under development. Literature review of duty-cycling has been started.

The other approach focused on the **F-MAC** protocol, where a state of the art study of hybrid CSMA-TDMA protocols has been performed. Furthermore, in this context it has been proposed a MAC oriented solution for diminishing the “funneling” problem near the sink, the simulations for validating the new design have been started this year. In the next report the result of the simulations will be included.

Regarding mobility framework study, an analysis was performed on different mobility models and mobility aware of MAC in WSN. As result of literature analysis the key parameters to identify mobility models have been defined, contact and inter-contact duration. The mobility models have been integrated into the simulator engine, being prepared for performing simulations in the following months of the project covering the following scenarios: mobile M2M devices form a capillary network and are in an area with fixed nodes whose positions are known and a sink node (gateway) whose position is known.

An address translation mechanism, to be implemented in resource constrain devices, has been investigated, on one hand, by setting up and measuring a real-world testbed including ZigBee, NFC and IP connectivity, and, on the other hand, by studying efficiency (on both IPv4 and IPv6), memory requirements and different performance regarding cellular technologies (GPRS, 3G, LTE...). The basis of the system is the mapping of devices in capillary network into virtual devices in the gateway.

T4.1 has also contributed to a Device Management protocol over SMS that is implemented and evaluated and on evaluation of the payload formats over the proposed Constrained Application Protocol (CoAP) protocol for capillary networks. The payload formats of interest (XML, JSON, EXI, CSV, Protobuf and MessagePack) over CoAP protocol was evaluated for efficiency (i.e. battery, memory and bandwidth consumption) in real

network conditions for parsing processes of messages sent from the server. The basis is resource oriented approach for device management of the constrained device.

T4.1 has investigated several MAC protocols, listed below.

MAC protocol for high number of devices.

The DPCF protocol (Distributed Point-Control Function) is being implemented in a C++ simulator. In addition, two conference papers have been submitted to two international conferences with:

1. the energy-efficiency evaluation of a cooperative approach that will be integrated into the DPCF protocol, and
2. the analysis of the conditions under which cooperation can be helpful in low-rate capillary networks formed by simple M2M devices with constant (non-adaptive) transmission rate.

MAC protocols for reducing the funneling effect that appears near to the sink.

The main contribution in this context is to include priority based access for satisfying heterogeneous requirements such as emergency situations, real time applications low battery supplies. Its achievements include the selection of the appropriate model, and the beginning of simulations. The next step include to complete the simulations as well as to prepare a conference paper with the obtained results.

MAC protocol designed for multihop scenarios.

It applies where data are being collected throughout the network and reported to the sink. In such situations, a highly congested traffic is appearing around the sink, which results in an increase to the dropped packet probability and power consumption due to continuous retransmissions. In this context, a hybrid MAC protocol is proposed which supports both CSMA and TDMA according to the traffic. More specifically, all the nodes perform CSMA by default unless they receive a beacon by the gateway and start performing TDMA. At this time, an accurate simulation platform has been created in MATLAB, where hybrid access schemes are being investigated. Next steps include to obtain an optimum threshold for the switching rate between the CSMA and TDMA.

MAC protocol designed for mobility scenarios

T4.1 has been working on a mobility estimator, like a 'guess who' algorithm, to distinguish the current mobility model among a series of known mobility models and patterns. We have also working on a MAC and routing approach which is mobility aware and adapts some parameters to the current mobility model. Then a novel algorithm has been developed by using simulation tools; a number of investigations on mobility were performed with an algorithm for estimating mobility pattern of mobile nodes.

3.3.9.1 Technical achievements

The technical achievements related to T4.1 can be summarized and categorized as follows:

- **Novel MAC protocols**, focusing different aspects and suitable to be used depending on the use case addressed:
 - The DPCF protocol with duty cycling mode has been implemented in wireless motes in order to evaluate its energy efficiency. This work complements previous simulation and theoretical works and shows that the combination of IEEE 802.11 DCF and PCF in distributed M2M capillary networks with collaborative M2M gateways can improve the performance of the network in terms of throughput, delay and also in terms of energy efficiency. The obtained results were reported in IR4.3 and a technical paper was written and submitted to an international conference. Next step will be to integrate the whole contribution of DPCF and all the conducted results into a journal paper.

- Following the proposed hybrid contention/reservation MAC protocol, which decides on the access mode to be used, based on the trade-off between the expected throughput and protocol complexity, we extended our work by proposing a novel analytical framework. Specifically, the expected throughput can be predicted by exploiting a queueing theory analysis, which evaluates the performance of both contention based and contention-free access schemes. Furthermore, our proposed MAC protocol has been evaluated in order to provide comparison results to IR4.3 in terms of throughput (K12) and reliability (K9).
- In addition to mobility models, partners have investigated to MAC protocols that exploit the mobility models estimator, namely LA-MAC and DA-MAC which are respectively Low-Latency Asynchronous MAC and Density-Aware MAC. They both propose to adapt their behaviour to network and traffic dynamics so as to better serve devices with respect of their QoS requirements.
- **Device reachability and addressability for data connectivity:**
 - The heterogeneous connectivity solution is now under evaluation so as to provide the last WP4 related results in IR4.3. In order to achieve this purpose, two main KPIs have been used. Efficiency is calculated as the relationship between real data sent versus the total amount of bits aired (including headers). With some techniques proposed, 80% efficiency rates can be reached. Finally, energy consumed per message is calculated using TST hardware platform.
 - MOBILITY MODELS - Different mobility models have been investigated and then gathered in a tool that acts as an estimator of the mobility model that best fits with the one experienced by either a mobile device or a group of mobile devices. This estimator is hardly assessable by KPI since it is just a tool that has been then exploited in MAC protocols. Nevertheless, the study on mobility models and the derived estimator can help to bring knowledge on mobility to any solution that would require such knowledge.
- **Payload reduction for supporting MAC efficiency:**
 - Application-layer protocol and payload reduction were evaluated with the final aim to calculate efficiency, i.e. complete payload size and battery consumption of HTTP/XML against CoAP/CSV in the live network. Evaluation showed that device that utilizes CoAP/CSV instead of HTTP/XML spends 13.2% less battery and that packet size is reduces by a factor of 4. Influence of payload reduction on complete EXALTED System is also considered. Wireshark is used for analyzing traffic in the network, while battery consumption is computed utilizing Android powered device for the parsing processes of large number of messages sent from the HTTP and CoAP server.
- **IP address assignment**
 - The IP address assignment analysis for the LTE-M terminals and assignment of the IP addresses to M2M devices behind the M2M Gateway is further investigated by mapping with other proposed algorithms and the EXALTED system.

3.3.10 Task 4.2

The goal of Task 4.2 is to design an IP based End-to-End (E2E) networking system for M2M communication. In this respect, its major achievements were:

- Design of a joint addressing and radio architecture for vehicular communications
- Design and implementation of address auto-configuration mechanism with DHCP-PD and DHCP default route
- Description of three vehicular networking scenarios

In T4.2, topics related to IP networking and IP communications between vehicles in particular have been studied. An IP addressing architecture for vehicular networks has been proposed. Then the description of addressing architecture has been adapted, considering a capillary network as a generic case of vehicular network, and included into IR4.2.

Then V2V2I communications and VIN conversion to IPv6 address or prefix have been investigated. For V2V2I, an analysis of the state-of-the-art for IPv6 addressing protocols (DHCP, Prefix Delegation, ND, Mobile IPv6) was performed. The proposed method was compared against ETSI-ITS and IETF standards.

An IP/ZigBee address translation mechanism envisaged for M2M Gateways has been defined. Selection of best technology, characterization of the efficiency of the method and a first integration on real equipment has been performed.

An IP/Capillary address translation for the IP devices (for example 6lowpan) that are behind the gateways in the capillary networks has been investigated. The gateway architecture whose goal is interoperability between 6LoWPAN and external IPv6 networks was analyzed. The gateway does the compression and decompression of IPv6 packets; the gateway also performs a mapping between 16 bit short addresses and the IPv6 addresses for both the external IPv6 networks and 6LoWPAN. The gateway may maintain internal and external device address mapping tables.

3.3.10.1 Technical achievements

The technical achievements regarding Task T4.2 are summarized below.

- **Address translation mechanism:** Finalization of the study about strategies for implementing ZigBee to IP address translation mechanism programmed on M2M Gateways. Selection of the optimum choice for being used on M2M devices oriented to SMM scenarios. Programming of the selected option in real M2M devices and performance evaluation of results. All data regarding state of the art study, implementation and measurement is included in D4.2 document.
- **IP to Capillary Address Translation Schemes, IP to 6LoWPAN:** Overview of the existing translation mechanisms between IPv6 and 6LoWPAN addresses and router and gateway functionalities. Analysis and proposal of the optimal solution for IP to 6LoWPAN address translation on M2M-Gateways. Definition of the M2M-Gateway functionalities needed for address translation.
- **6LoWPAN protocols:** Definition of the mobility types and overview of the existing 6LoWPAN protocols and emerging new protocols. Analysis of the mobility protocols features in 6LoWPAN (MIPv6, HMIPv6, NEMO, MANEMO etc) and routing protocols (ROLL and MANET based and Neighbour Discovery) for 6LoWPAN.
- **Addressing and Routing Schemes for Capillary Networks:** A detailed study of the state-of-the-art for addressing and routing mechanisms in Future Internet has been done. This work was presented to partners during the 4th General Assembly. The design of the addressing and routing mechanism for V2V2I communications (that can be seen as C2C2I communications in a more generic manner) is close to be finished. Most of the steps in the proposed mechanism have been done, leading to the improvement of standard addressing and routing protocols (such as NDP and DHCPv6). All details about the proposed addressing and routing mechanism for capillary networks can be found in D4.2.
- Elaboration of the **common evaluation framework** as well as providing the KPIs results regarding the E2E connectivity scenario. This work is detailed in IR4.3 and also provided to WP2 as an input for the elaboration of D2.4.

3.3.11 Task 4.3

This task aims to provide a Device Management solution for the EXALTED architecture to facilitate device deployment, firmware update, remote administration, service installation, policy application, logging and reporting.

Task 4.3 started with the study of existing solutions, mainly:

- OMA-DM and TR-069, all based on XML. But they are not suited for Exalted, which needs a lightweight protocol.
- OTA is an alternative solution. Lightweight and security mechanism are already in place. But it may not satisfy all the Device Management needs, such as Get, Exec, Replace, Add, etc, methods
- A protocol derived from OMA-DM was under study:
- Keep OMA-DM Management Objects
- Keep OMA-DM principle : Setup phase & Management phase
- Keep OMA-DM security mechanism
- Key difference : use key/value instead of SyncML representation

Based on a firmware update scenario, the proposed protocol leads to a reduction factor of 5 with respect to the payload size.

T4.3 has evaluated a proposal of device management payload for resource consumption, defined device management architecture interfaces, simple device management procedures and mapping for OMA-DM and REST.

A testing environment has been provided by in a Data Center for the Device Management evaluation.

T4.3 worked on an evaluation of an M2M Device Management over SMS by using CoAP message semantics. The motivation was to address a large number of SMS enabled terminals used today. The GET and POST methods are implemented for CoAP over SMS between devices in real network conditions in order to evaluate SMS efficiency for device management procedures. The next step is to evaluate an SMS Broker as a Device Management Application Server equivalent. In this case, the SMS transport efficiency should be better when sent directly from an SMSC. In addition, two papers are planned for the following proceedings: IEEE Globecom 2012 and Infocom 2013.

Then, an OMA-DM v1.x compliant lightweight solution has been finalized. This solution enables service providers who wish to reuse existing OMA-DM v1.x servers to continue managing existing OMA-DM enabled mobile devices and to incrementally support M2M devices. An adapter proxy is inserted in the communication chain, between new M2M devices and the existing OMA-DM server. This adapter provides a 2 ways message conversion: OMA-DM message to Exalted Lightweight DM message. The cost of this solution is minimized as existing OMA-DM servers are reused “as is” without any change. The complexity of the adapter proxy is reduced to message conversion and encoding scheme. Lightweight DM message definition and syntax have been finalized. Method to create and to parse lightweight messages is defined.

A device management solution based on SMS has also been finalized. This solution is used to manage M2M devices that are out of reach of 2G/3G/LTE-M data connectivity. Lightweight CoAP messages are exchanged over SMS between the DM server and devices.

A paper describing this CoAP over SMS solution has been written.

Work done on the security has been mostly dedicated to address the scalability issue without compromising the overall security. Architecture with devices sharing the same key among a capillary network is considered. Favourite architecture is a distributed Device Management with a Device Management Agent located on the gateway to factorize some device management functionality.

The proposed OMA-DM v1.x compliant lightweight Device Management solution reduces OMA-DM messages by 85% while maintaining the same protocol and functionalities.

Evaluation methodology for device management has been elaborated. KPIs pertaining to various DM solutions have been assessed. The outcome of this study will be documented in IR4.3 and D2.4.

- A power cut scenario has been detailed for a Smart metering and monitoring use case. This serves to evaluate the payload reduction of DM solutions.
- Based on the aforementioned scenario, ELFOMA achieves 88.8% in payload reduction.
- While CoAP DM over UDP and SMS achieve 67.67% in payload reduction :
Device Management over CoAP: In order to efficiently utilize proposed device management algorithm, a mapping of device management in the system for different use cases is done: (1) for communication between Gateways, SMS is proposed as a transport with embedded CoAP messages, (2) communication behind Gateway in the Capillary network, a “pure” CoAP transport is leveraged. CoAP device management is evaluated for power-heater scenario: one message with 3 replace commands for updating device info. The device management scenario is evaluated for the previous message for related KPI measuring battery consumptions and transmission packet size in 50 performed tests. The evaluation showed that transmission payload size exchanged between 2 peers is 3x smaller, and that messages sent using proposed CoAP DM consumes 20.8% less energy than a reference native OMA DM protocol SyncML message.
- The Abstract Syntax Notation (ASN.1) encoding rules have been studied as a possible representation for the device management commands to replace the current SyncML as specified by the OMA-DM. This work has been reported in document D4.3. A nice aspect of this representation is its compactness and its ability to encode whatever protocol to ELFOMA to the new protocols currently specified in the various OMA-DM standardization groups.
- End-to-End security had been specified and prototyped from end-device to M2M server. So far only classical smart cards have been used as a secure element but nevertheless the capacity to bring advanced security features to a low-end device has been demonstrated in lab. Code developed during these experimentations has been recycled in the WP7 for the security sub-testbed. All results of the work done on security and device management, that is mostly the management of the secure element and its credentials have been reported in deliverable D4.3.

3.3.12 Task 4.4

Task 4.4 was focused on the design of novel coding schemes and communication protocols aimed to improve energy efficiency and reduce network congestion in (large) M2M capillary networks.

To that aim, research was carried out on decentralized source coding techniques, which are capable of dealing with spatially- or temporally correlated sensor observations (e.g. environmental monitoring scenarios). These techniques are expected to reduce the amount of redundant information sent by the sensor nodes as well as the total network traffic. In this context, an extensive review of the state of the art was performed.

Research efforts have been also focused on investigating joint routing and scheduling algorithms that will efficiently handle the capillary network energy and the network congestion near the sink. In this context several techniques have been investigated including, for the network layer, congestion avoidance routing or data centric routing and for the MAC layer, adaptive scheduling techniques and suitable duty cycle MAC protocol. Simulations for validating the new design have been started this year.

T4.4 investigated the analytical assessment of decentralized source coding techniques for random field estimation with capillary M2M networks. In this context, we have analytically analyzed the performance of the Quantize-and-Estimate encoding strategy when channel state information is not available at the sensor nodes. Besides, we have also derived the optimal transmission order for the Compress-and-Estimate strategy.

In addition to this, we have also studied transform coding techniques based on the Karhunen-Loève (KL) transform. In this context, we tackled the problem from different perspectives. On the one hand, we adopted beamforming at the sensor nodes in order to implement the Karhunen-Loève transform in the air. In this setting, we analyzed the impact of imperfect phase synchronization and independent duty cycles at the sensor nodes. Some results have been already published (IWM2M Workshop) and recent results have been submitted to international conferences such as ICC'12 and ICASSP'12. On the other hand, we addressed a realistic scenario where sensors transmit their observations by means of a contention-based Medium Access (MAC) protocol to the Gateway. Here, the Gateway implements the aforementioned (KL) transform and compresses the sensors' information aimed at reducing the traffic load at the LTE-M network. Preliminary results have been submitted to FUNEMS'12.

T4.4 has also developed and evaluated a new node clustering protocol. This protocol is designed to be fully distributed without any dependence on time synchronization modules or protocols. Hence, it is different from the current node clustering protocols that exist in the literature. No time synchronization property enables the protocol to be able to quickly adapt to changing conditions and also be scalable to a multi-hop setting in a large area of deployment. Then, this protocol is used to aggregate the collected data in a capillary network and deliver the resulting information to a single gateway. This version of the protocol included four different cases in performance comparisons: (1) no-clustering, (2) only-in-cluster CH reselection, (3) only region-wide re-clustering, and (4) re-clustering including in-cluster and region-wide updates. An emulation code has been developed. Initial results demonstrate that performance improvement is observed in extending network lifetime and relieving network hot spots. However, it was noticed that the emulation code had to undergo a significant structural review so as to better reflect the estimated network lifetime. Significant changes were made to it, which helped making a more accurate network lifetime evaluation. The code structure was still sequential and additional evaluations had to be made. The resulting work was presented during the WP3/WP4 physical meeting in Stuttgart. Later, a final version of the emulation code was prepared, that has major differences from all previous versions in that the structure of the code enabled parallel operation of node-centric events via introducing node states. The previous code on the other hand was based on sequential processing of network events, which usually over-estimated network lifetime since overlapping events were double counted. Hence, this newer version significantly improved the accuracy of evaluation of network lifetime.

A third activity in T4.4 consists in research on mediated gossiping in large scale capillary networks. This work enables a high level coordination between gateways controlling individual capillary networks. By doing so, related data and queries can be directed and related with correct and most relevant locations dynamically.

Another part of the work performed in T4.4 is about the MU-diversity with beamforming techniques where our prime targets are to efficiently handle the aggregation of a large number of sensor nodes around a fusion center (FC) as well as to considerably reduce the nodes' channel state information that is fed back to the FC. In this context, by considering a highly time correlated fading channel and by employing differential quantization techniques we have managed to obtain a considerable reduction on the amount of bits, with CSI information, that are sent back to the FC by the users. Furthermore, we have performed some preliminary, and then extensive simulations regarding a MAC protocol in which joint scheduling and routing techniques have been considered for efficiently handling the capillary network energy and the congestion near the sink. At that time we have managed to create an accurate simulation platform in Matlab, where hybrid access schemes were being investigated.

A final activity was the study of selecting the optimum cluster head for capillary networks, obtaining fruitful conclusions about the trade-off between network lifetime and outage probability. Future steps were provided as well.

The technical achievements in T4.4 can be summarized as follows:

- **Data Compression at the M2M Gateway:** We have been working on our previously proposed data aggregation technique at the GW. In particular, we have designed a multidimensional filter in order to exploit temporal and spatial correlation of sensor data. After exploiting data correlation, data is compressed to a given number of coefficients that are sent to the application server. We have seen that this signal processing technique can significantly reduce the traffic in the LTE-M network when data is highly correlated. Related to this activity, one conference paper (ICASSP'12) has been presented and one conference paper (EUSIPCO '12) accepted for publication.
- **Beamforming and MAC protocol:** Continuing our work concerning the MU-diversity with beamforming techniques we have consider a highly time as well as spatial correlated fading channel and by employing differential quantization techniques we have managed to obtained a considerable reduction on the amount of bits, with CSI information, that are sent back to the FC by the users. Furthermore, we have started to perform extensive simulations regarding the MAC protocol where hybrid access schemes are been investigating. Our next steps include a routing algorithm that will considerable reduce the congestion around the CH.
- **Cluster head selection:** working has been performed on the study of selecting the optimum cluster head for capillary networks, obtaining fruitful conclusions about the trade-off between network lifetime and outage probability. Future steps provided as well.
- **Symbolic Aggregation Approximation:** work was performed on a data aggregation mechanism based on Symbolic Aggregation approXimation (SAX) method. The performance of the proposed mechanism was evaluated by changing the granularity of data using SAX and creating high level abstraction and representing them as patterns. Event processing and pattern detection techniques were added to the proposed data aggregation mechanism in order to improve its performance. Initial performance evaluation of SAX was performed with event processing and pattern detection.

3.3.13 Task 4.5

This task was concerned with network health monitoring of sensor / actuator to ensure that there are on-line, bi-directional, demand-response communications between sensor-actuators and gateways. This task is different from Device Management in a way that it does not only focus on identifying single stopped functioning devices but monitoring reliable operation and maintenance of the network is the main objective in this task.

As a first step, consolidated requirements were specified for this task driven from use cases introduced in IR2.1, 3GPP MTC, and ETSI. The different sets of parameters involved in this task were made explicit.

Then literature review and background study of current mechanisms and algorithms available in capillary networks were performed. Some algorithms that have been studied are: BOSS, MANNA, RRP, SNMS, WINms. Our current focus is categorizing existing monitoring and management mechanisms in different networks (Periodic reporting, Event-Driven, and Query-based), defining the evaluating metrics (i.e. number of transmitted bits/packets, overhead, frequency of reporting, energy spent per bit, etc. and study the most suitable algorithms for EXALTED. In addition to capillary network in the next step we have plan to explore the monitoring mechanisms for LTE-M devices directly linked to the LTE network.

T4.5 has also studied a hierarchical network construction for distributed control of devices by cluster head nodes. The distributed clustering protocol has been tested extensively with respect to its operational parameters.

The procedure that forms the cluster structure in the capillary network has now been finalised as two mechanisms: In-cluster Cluster-head role Rotation (ICR) and Multi-Cluster Re-clustering (MCR). ICR is a periodic decision making mechanism whose time period T_{in} of condition checks has been tested for its effect on protocol performance. It has been shown via emulations that T_{in} is most beneficial for $T_{in} = 20$ unit time periods. (A unit time period is defined as 10 back-to-back link-level packet transmissions, without the effect of MAC delays) For lower and higher values of T_{in} reduction in network lifetime was observed. Although for all test cases, the standard deviation of node energy levels are lower than what would be observed in the case with no ICR in place, a very large value of ICR ($T_{in} = 50$) deteriorates protocol performance by decreasing network lifetime. This showed that ICR must be performed sufficiently frequently in order to obtain noticeable gains.

An estimation module that assigns accurate initial values to the CH energy consumption E_{cost} has been implemented. This module simply uses two consecutive HELLO messages and disseminates generated data rates in local areas. With this, nodes are able to predict the later incoming rate from potential CH nodes, should they be selected as a CH as well. As a result, the aggregated data in the CH nodes are better tuned to initial network conditions, which are later refined by real traffic streams that are fed to the CHs.

Initially, ICR and MCR were evaluated separately in order to understand how specific parts of these mechanisms are affected by their parameters. Then, a whole protocol with ICR and MCR for network-specific parameters, such as node deployment density and initial variation of device energy resources, was tested.

The device deployment density has a major effect on how many CH nodes are eventually needed to cover and effectively manage a reasonable number of devices within a given area. Test results has shown the DISC protocol scalable to differences in node density, as the resulting average energy consumption figures show similar angle of decline, and networks with different density have similar energy variations over time.

Test results have demonstrated that a combined ICR&MCR protocol (DISC) can actually reduce collected data volume while applying re-clustering only within limited parts of the network at locally determined time instances. The protocol is also found to be scalable to difference in network density, whereas increasing energy heterogeneity unsurprisingly reduces network lifetime.

Task 4.5 defines a set of functions to monitor network status, detect network faults, to maintain normal operation and improve network efficiency. To perform these tasks, network monitoring needs to send queries and collect information from network devices to analyse the information. We prepared a detailed list of the queries required by network monitoring server and continue to work on identifying special requirements for network monitoring to be compliant with the properties and constraints of EXALTED (large scale, low cost, low resources consumption, reliable, scalable, and configurable).

Therefore we have chosen a new hierarchical solution for network monitoring, by distributing the Monitoring Module in cluster heads, gateways, and eNodeBs. In this approach, Information is organized in different modules and there are agents in each network device to collect the information and report to an upper-level network that has a view of the more complete network information.

The proposed framework enables the intermediate devices (Gateways, Cluster Heads) to combine their monitoring status with the results from connected M2M devices to capture the status of the network. A hierarchical architecture tackles scalability by applying monitoring policies in different network levels to reduce monitoring network traffic load over the LTE/LTE-M network.

The proposed software architecture for network monitoring has several advantages over the current solutions. Scalability is the main design consideration to support a large number of M2M devices. In addition, it introduces standard interfaces allowing interoperability with other EXALTED architectures such as device management and self-diagnostics.

A monitoring scheme based on Pachube middleware, being able to receiving information from the nodes in a capillary network has been implemented and a first basic demonstrator has been performed.

A draft document was completed outlining the architecture options for the network monitoring architecture and the recommended approach for EXALTED. The document is awaiting feedback from the EXALTED group.

- **Lightweight Monitoring Mechanism:** development of a Pachube client embedded on TST's M2M devices that enables in an efficient manner (using CSV messages) to monitor the status of the different nodes. Characterization of resultant throughput. Evaluation of next steps regarding node monitoring.
- A hierarchical approach to network monitoring has been proposed. The proposed framework enables the intermediate devices (Gateways, Cluster Heads) to combine their monitoring status with the results from connected M2M devices to capture the status of the network. A hierarchical architecture tackles scalability by applying monitoring policies in different network levels to reduce its impact on the traffic load over the LTE/LTE-M network.

Lightweight Monitoring Mechanism: this technique has been included under scenario 2 (device management) and it has been compared against the resultant payload size of the aired packet, as the solution is oriented to reduce this packet to the most. The real implementation is able to reach up to 150Kbps at each node, limited by the capillary interface selected (ZigBee), transmitting 20Byte payloads. The Gateway is able to aggregate the data and encapsulate it through the HTTP session, obtaining 80% payload reduction rates.

3.4 WP5

WP5 aimed at the definition of low cost, automated authentication and device provisioning solutions as well as securing the provisioning and data transmission operations in different contexts (use of data gateways, use of broadcasting or relaying techniques) for efficient and secure M2M communications over 3GPP or IP networks.

3.4.1 Overall Progress of WP5

WP5 work was spread over three tasks: T5.1 (Low cost provisioning and security), T5.2 (security mechanisms to be used for broadcast and multicast operations), T5.3 (Security solutions to secure networks using P2P relaying).

Task 5.1 was spread over the first sixteen months of the project and would have benefited to take place as a background activity during the whole project length as the “low cost aspect” is also impacting security solutions defined in tasks 5.2 and 5.3. This constraint led us to organize our activities in consequence.

Task 5.1 has resulted in the production of D5.1 public deliverable; This report deals with network access security for M2M devices in 3GPP (3G, 3G+,LTE, LTE-M) networks and addresses architectural topics for application level M2M security in “generic” (not necessarily 3GPP) wide area IP networks. It has involved a

close collaboration with Work Package 6 team on the definition and prototyping of an “**applicative secure element**” embedded in M2M devices and a continuous collaboration with WP2 team dealing with Exalted M2M architecture.

Task 5.2 has resulted in the production of D5.2 public deliverable. This report focuses upon the use of broadcast and multicast techniques to perform device management and software provisioning on a very large number of devices. It addresses the associated security issues. Task 5.2 has involved close cooperation with WP4 team on the topic of M2M device management and with WP3 team regarding the use of broadcast facilities in LTE/LTE-M networks.

Task 5.3 has resulted in the production of D5.3 deliverable. This report deals with ways to bootstrap internal security in standalone capillary networks which use multihop communications. It also proposes different security models to secure the connection of multihop capillary networks to wide area networks. Task 4.3 has involved collaboration with WP4 team on the topic of traffic aggregation.

The main contributions of WP5 group revolve around the following points

- Contributions to the definition of a new type of an embedded secure element either used for securing 3GPP network access (embedded SIM) or securing M2M applications (MIM)
- Sharing of secure element to secure multiple layers of data communications
- Low overhead security
- Business drivers and architecture solutions to achieve End to End security for M2M communications
- Bridging LAN and WAN security ; benefits and possible solutions
- Methods to achieve security bootstrap in multihop capillary networks
- Methods to bootstrap security for broadcast/multicast communications
- Use of MBMS with lightweight GBA to securely distribute software updates to a large number of M2M devices connected to 3GPP networks.
- Lightweight key management methods in broadcast/multicast M2M communications.

We believe that those contributions constitute reasonable results in accordance with the initial project proposal.

The work of the group resulted In terms of dissemination (directly or indirectly through member companies) in more than 14 contributions to 3GPP and ETSI M2M work groups, filing of more than 10 patents by group members, the submission of four papers (two accepted at time of writing), the agreement for presenting the group results in three M2M international conferences, and the participation to the writing of a book to be published on M2M communications.

The following sections provide further details upon the most significant achievements.

3.4.2 Embedded secure element

The traditional SIM form factor has proved over time to be ill suited to small M2M devices for the following reasons:

- Various types of appliances are now becoming connected, some of them featuring a very small form factor where the accommodation of a traditional SIM connector is not easy.
- M2M applications involving specific environmental constraints (heat, vibrations, humidity,...) or usages (e.g. alarming) may impose the SIM to be soldered on the device.
- Some devices need to be provided “ready to connect” to the end user, requiring to fit the SIM in the device at production or distribution. Distribution and operating costs must be very low because the average revenue is currently very much smaller than in the mobile consumer market.
- Subscription change by SIM swap when devices are in inaccessible locations is not possible and dictates the need to support over the air subscription management on M2M devices.

These reasons led the GSMA In November 2010, to announce the creation of a task force to “explore the specification of a remotely activated embedded SIM” in embedded devices, which in most cases cannot be removed.

This event probably marks a turning point in the history of the SIM card, as the management model for an embedded SIM differs significantly from the one of the traditional SIM, for which the initial personalization occurs at manufacturing time.

WP5 has contributed to the definition of the embedded SIM (eUICC) through the action of its member companies. The case of an embedded SIM holding multiple M2M applications credentials in a multitenant environment (the credentials associated to the different eUICC applications belong to distinct business entities) has been explored. Different business scenarios corresponding to distinct security models have been identified and described.

The cost impact upon security resulting from the introduction of the eUICC has also been investigated. A cost breakdown of security in existing LTE network was first proposed.

The conclusion is that, if the cost of the embedded secure element is likely (at least in the years following introduction) to be comparable with the cost of traditional SIM cards, very significant savings will results from the automated subscription delivery and activation costs.

The eUICC is a secure element controlled by the mobile network operator and used primarily for securing 3gpp networks access. A derivation of the eUICC leads to the “*applicative secure element*”, packaged as a simple peripheral connected to an M2M device via industry standard interface (Sp, I2C bus), and used primarily for application security. We have also in collaboration with WP7 explored this type of secure element and the associated security management model. This work led to one of the prototypes presented by WP7.

3.4.3 Low overhead security

LTE-M or M2M devices part of Wireless sensors networks may be highly constrained in terms of energy consumption. WP5 has investigated the overhead linked to security and proposed “low security overhead security solutions”.

The impact of the security upon energy consumption of the device has been investigated by considering three factors:

- The power consumption linked to the execution of cryptographic algorithms inside the device.
- The power consumption linked to the need to data overhead associated to security

- The power consumption linked to factors related to infrastructure choices, e.g.: periods between re-authentications, number of simultaneous layers of security.

D5.1 has identified a number of “energy efficient” block ciphers reducing the energy required for cryptographic operations. The impact of using short MAC upon security in an attempt to reduce the data transmission overhead has also been investigated. Finally, for 3gpp networks, proposals to collapse security layers in an attempt to minimize the architecture overhead have been formulated.

3.4.4 End to end security

The M2M architecture used in the EXALTED project involves an M2M service platform operated by an M2M service provider. Pretty much as a PABX enables on demand communication between handsets which are not directly wired together, the M2M service platform is expected to provide interoperability between independent M2M applications or devices. The introduction of M2M service platform in the M2M architecture lead to a well-known “trapezoidal communication model” similar to the one used for Voice over IP or telephony communications and illustrated in Figure 2.

From security standpoint, the hop by hop security model where each hop of the communication path is secured using a distinct set of credentials managed by different business entities, is the most widely adopted model.

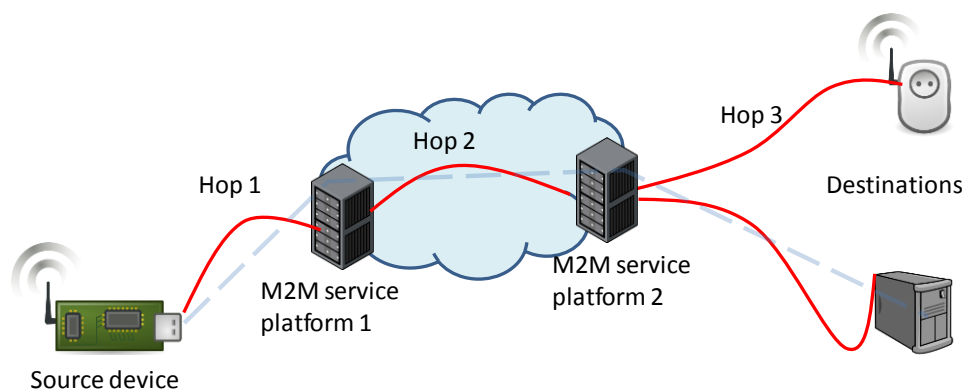


Figure 2: Trapezoidal communication model.

This security model is based on a circle of trust existing between M2M service operators and imposes upon them a number of constraints which are detailed in D5.1. The WP5 team has identified and described a number of business drivers for supporting an “**end to end security model**” in which a single set of credentials is used to secure the data communication from the source to destination. The underlying reasons are described in D5.1 and in D2.4.

We have investigated the possible solutions to implement end to end security in the Exalted or in the ETSI M2M architecture. In particular we have shown that the resulting architecture opens the possibility to split the responsibility of the M2M service provider between 2 independent business entities: the M2M service provider and the trust manager. The benefits of this have been identified and described.

3.4.5 Bridging of LAN and WAN security

M2M applications often involve the combination of local area network (LAN) and wide area network (WAN) communications. In this case, the devices typically transmit their data through a proximity network (LAN) up to a gateway making the bridge with the internet. Then the data is routed through the wide area network up to the application server, either directly or via an M2M service provider.

In order to secure the data stream, devices usually need to secure their local connectivity. Popular communication protocols such as Bluetooth or ZigBee offer network access security between the devices or between the device and gateway. The execution of the security bootstrapping process to define security credentials is generally under the responsibility of the device owner.

The security of the data transmission after the gateway and up to the destination(s) is part of the application security domain. The responsibility for credential definition belongs to either the M2M application provider or to the M2M service provider when such provider is involved.

Application security may either stop at the gateway level or extend up to the devices part of the capillary network. In such a case, the data transmitted in the local area network will undergo a double ciphering: one linked to the LAN network security and the other tied to the application security as illustrated in Figure 3. This for small devices can be inefficient and particularly so if they are constrained in energy or computing power.

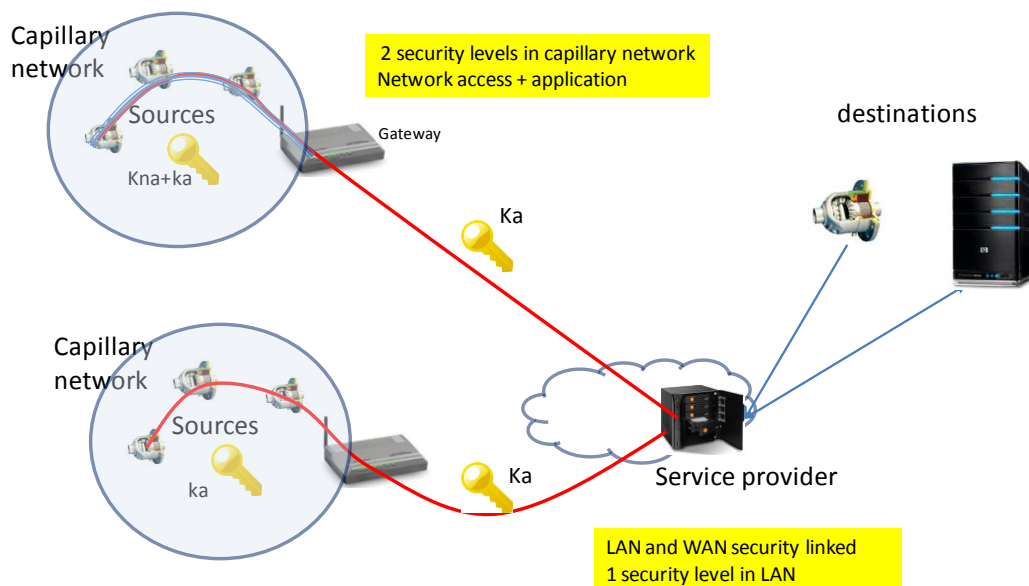


Figure 3: separate and bridged LAN and WAN security

WP5 has investigated the possibility to bridge the LAN and WAN security resulting in a single set of credentials in the LAN and in the WAN. In this case, the M2M service provider can offer as a service to remotely manage the LAN security thus relieving the device owner for the responsibility to do so. We have proposed solutions to achieve this goal and have shown that the remote management of LAN security by an M2M service provider makes possible the support of new use case scenarios to connect capillary networks located in different LANs. We have detailed 2 such scenarios and proposed associated security solutions:

- One device belonging to one capillary network, connecting and relaying its communications via a guest capillary network when in a mobility situation.
- Devices belonging to one capillary network, being able to relay their communications via another foreign network in the immediate neighbourhood

3.4.6 Security bootstrap in capillary networks using multihop communications

Task 5.3 was dedicated to the use of relaying or multihop communications in capillary or infrastructure networks. In multihop capillary network we studied group device pairing mechanisms and discussed their application in constructing authenticated group key agreement protocols. The mechanisms were classified into two categories of protocols: with and without trusted leader. We showed that protocols with trusted leader are more communication and computation efficient.

Our study considered both insider and outsider adversaries and presented protocols providing secure device pairing for uncompromised node even in presence of corrupted group members. Three new group device pairing protocols were proposed, namely group numeric comparison, group MANA II, and multichannel group device pairing and communication efficiency of Nguyen and Roscoe's HCBK protocol and Laur-Pasini SAS-based group key agreement protocol were enhanced.

3.4.7 Use of MBMS with lightweight GBA for device management in 3gpp networks

In the scope of task 5.2, WP5 has investigated the possible use of broadcast and multicast technique to disseminate the same device management commands or software updates to a large number of devices. For device provisioning occurring in 3GPP networks, D5.2 proposed to use the Multimedia Broadcast and Multicast Service (MBMS) in conjunction with either ELFOMA (the lightweight device management protocol proposed by WP4 team) or OMA device management solutions. We have investigated the security aspects of this proposal. The Generic Bootstrapping Architecture (GBA) is at the core of the MBMS security and we proposed a lightweight version of the GBA based upon a CoAP mapping replacing the traditional HTTP mapping. In order to validate the added value of the solution, we compared a sample HTTP based GBA exchange with the CoAP equivalent and showed the expected benefits of using CoAP for the GBA exchange.

3.4.8 Use of broadcast and multicast for device management/software update in IP networks

Task 5.2 has also considered the use of device/multicast techniques for device provisioning in "Generic IP" networks (possibly, but not necessarily 3GPP networks) and identified security solutions to remotely manage devices located behind a gateway, taking into account the specificities and the threats associated to the LAN part of the transmission (transmission of data behind the gateway to the devices).

Our contributions on this topic are focused upon 3 points:

- How can a capillary device bootstrap its security with a remote device management server located in a wide area network when broadcast/multicast is being used. In particular we proposed an enhancement to the ETSI M2M architecture to define a new service capability layers enabling to bootstrap broadcast security.
- The initial security bootstrap usually enable secure transmission of one or several group keys to all devices candidates to receiving data. We propose a solution (based on the use of Key Derivation Keys) to minimize the key distribution overhead for applications involving multiple group keys.
- Group keys have usually to be renewed whenever devices leave or enter the distribution group, possibly resulting in significant overhead. We investigate and propose a solution to reduce this overhead.

3.5 WP6

WP6 aimed at improving different aspects of M2M devices such as energy efficiency, device self-diagnostic and self-healing and M2M device security. WP6 released four (4) deliverables D6.1, D6.2, D6.3, and D6.4.

3.5.1 Overall Progress of WP6

Task 6.1 focused on the broad subject of improving energy efficiency in constrained M2M devices (meaning low cost and low power processing devices) with a particular interest in energy management in capillary networks, at MAC level and at LTE NAS protocol level. These work items are described in the deliverable D6.2 which also compiles results related to energy efficiency of other EXALTED work packages.

Task 6.2 focused on improving the Linux Kernel when used in M2M gateways. Public deliverable D6.1 provides a study that covers dynamic voltage scheduling (DVS), system improvement and an interrupt filtering solution.

Task 6.3 described a framework for a self-diagnostic mechanism targeting M2M devices as well as networks of M2M devices. The results of task T6.3 were published in D6.3.

Task 6.4 aimed at defining a new low cost, low power and energy efficient pairing mechanism for constrained devices that materializes as a secure element for M2M devices. These results were described in D6.4.

3.5.2 Energy Efficiency

This task started with literature survey on gateway functionalities on sensor networks, 3GPP's LTE and MTC specifications and ETSI's M2M service requirements with a focus on devices and on sleep mode management in data collection scenarios. Different constraints peculiar to M2M networks were drawn out such as the support of various communication demands and capabilities and the support of large number of devices whilst maintaining the energy efficiency of the devices. These activities were performed as a combined effort with WP3 and WP4.

3.5.2.1 Hierarchical capillary network structure

One application of M2M networks consists in the monitoring of phenomena related to environment, delivery of summarized information to related end-users, automated data storage and processing servers that reside somewhere else. This is achieved by cooperative collection of regular or instantaneously generated data by multiple measurement devices, usually wireless sensors, to the gateway in multiple transmissions. A multi-hop transmission is required when data is generated far away from the gateway location and a direct transmission is either too costly or simply not possible by the device. However, as multiple data traffic flows are generated at a large number of network locations simultaneously, although the data rate of these flows may be low, the end result is a high traffic load on forwarding nodes where these flows merge. Such locations emerge as Network Hotspots, locations where nodes are under heavy burden of data forwarding, which leads to early depletion of their energy resources as compared to devices that do not have much traffic load. Hence, an imbalance in traffic load is likely to exist in multi-hop networks and is especially expected for M2M networks with large number of data sources.

To tackle the hot-spot problem, the energy consumption throughout the network should be equalized as much as possible. Towards this objective, different strategies can be taken, namely MAC level measures, routing level measures such as selection of best forwarding node, Cluster Head (CH) selection algorithms, and scheduling of individual traffics to ensure equalized load on forwarding nodes.

3.5.2.2 Energy efficient MAC scheduling

In M2M applications, various requirements arise, including the high number of devices, the low duty cycles, low power consumption, and traffic patterns that are based on a hop -by-hop and many-to-one logic towards the gateway. Trying to satisfy these requirements without considering device power consumption levels may considerably deteriorate network energy efficiency. In order to improve the energy efficiency of the network, two complementary MAC protocols are proposed. These protocols provide adequate solutions for collision reduction and congestion avoidance, thus help avoid unnecessary retransmissions of the same information, which consumes devices battery energy. The two protocols are complementary to each other in a sense that the MAC protocol for collision reduction is one-hop oriented, while the second one designed for congestion avoidance is based on multihop scenarios.

3.5.2.3 Duty cycle mechanism for LTE capable M2M devices

This mechanism aims at providing an answer to two requirements the EXALTED project identified as area of improvement regarding M2M communications. The first one is to be able to achieve better energy efficiency for LTE/LTE-M capable devices and the second one is to limit the risks of traffic saturation when M2M traffic and legacy traffic are competing for network resources.

Improvement to the device's energy efficiency is performed by introducing negotiated duty cycles. Negotiation happens at subscription level between the network provider and the M2M service provider. Intervals for data communications are scheduled and pushed to the device at NAS protocol level, first during the initial network registration procedure and eventually during each data transfer. The duty cycle enables offline intervals the device can use to apply strong power saving procedures up to a complete power off during offline intervals. Improvements in the NAS management of registration update procedures in order to maintain the device registration status over long offline intervals were also proposed. These improvements are a consequence of a timer management policy that is M2M device specific. They do not impact legacy systems as they are per device policies and, as a consequence, can be applied to M2M devices that are duty cycle capable only. The main result is that, when the device reaches online granted interval, it is not expected to perform full network registration procedure prior to initiating communication yet, its network registration status remains. Better energy efficiency is performed through significant reduction of system transactions at NAS level.

Traffic saturation can be avoided thanks to the control duty cycles enable over M2M communications. The network provider and the M2M service provider can decide when a device is authorized to transmit or receive data and when it is not. Carefully designing the windows of opportunity for M2M data communications, it is possible to regulate its traffic and move it or part of it to moments the network resources are underused by legacy users.

3.5.2.4 Enhancements to Linux Kernel for Energy Efficiency

M2M gateways, or high-end M2M devices, tend to use Linux as operating system since Linux is very popular for embedded systems. It is therefore interesting to seek for energy efficiency optimizations in a Linux embedded system.

Implementation of DVS in the Linux Kernel was detailed and a simple DVS algorithm was suggested.

An improvement over the tickless idle implementation was suggested in order to get a complete tickless system. Current tickless idle mechanism considers removing the tick event during idle mode in order to prevent regular wakeups. T6.2 considered the benefits of removing the tick event also during active intervals relying on high resolution timers to schedule tasks. The underlying idea is to improve the resources dedicated to useful tasks over resources dedicated to system tasks. The cost of such modification to the kernel is a difference in the task switching dynamics. Tasks with equivalent priorities do not interleave anymore as tasks consumes their allocated resources in a single run.

The interrupt filtering solution that was proposed is based on the idea that an efficient device should only wake up to tackle "interesting" tasks. Energy efficiency is reached as the complex Linux mechanism of handling interrupts is only invoked for valuable tasks while a focused mechanism discards uninteresting events and returns the system to sleep mode much quicker than the Linux scheduler would. A solution based on TinyOS, a lightweight and prompt to return to idle mode operating system, was suggested in the document.

3.5.3 M2M Device Reliability

Task 6.3 aimed at designing a self-diagnostic and self-healing framework for the M2M devices. The underlying idea is to improve the maintenance of large numbers of devices by introducing an autonomous device management which can also be described as a local delegation of some usually remotely performed device management tasks. The task worked in close cooperation with Device Management in WP4 to provide an interface for the remote device management system in order to reduce the number of transactions, hence to reduce the overall network resource cost of device management.

Guided by a set of updatable rules the device is able to decide which action results from a diagnostic it performed on itself with the resulting actions ranging from notifications to self-repairing procedures. The self-diagnostic capable device can also participate to a broader network diagnostic mechanism that is built upon the device self-diagnostic mechanism. Both mechanisms are described in the public deliverable D6.3 published in M18.

The diagnostic in the device is performed by an embedded self-diagnostic server that applies rules logic to a device context made of state variables. The logic of self-diagnostic is made of a set of hierarchical and interconnected rules that produces a diagnostic result. Based on this result a predefined or contextual reaction is initiated. Such a reaction ranges from “doing nothing” to launching a self-healing procedure should the diagnostic be interpreted as an indication something goes wrong in the device.

As it is defined, the diagnostic server may not be limited to local diagnostic. The diagnostic logic applies to local state variable but it is possible to locally maintain a set of state variables that represent the current state of other connected devices as provided by these devices’ own diagnostic servers. Interconnection of SDMs enables virtualizing the diagnostic resources and, if the network of devices is carefully designed, it becomes possible to get the status of a network addressing the SDM of a single device or at least, a limited number of them, considerably reducing the amount of maintenance traffic over a main radio link such as a LTE/LTE-M connection. A network status may not rely on a “per device” addressing of every devices belonging to said network (every request would transit through the main LTE/LTE-M link) but on a single request sent to the diagnostic server running in the device that acts as the device network access node.

3.5.4 M2M Device Security

Task 6.4 focuses on device pairing mechanisms paying attention to the low resources. Studies on M2M device specific threats were performed, leading to the definition of a set of requirements regarding device security.

Task 6.4 also produced interim report IR6.2 that details the pairing mechanisms and applies them to common EXALTED use cases (automotive, eHealth and smart metering use cases). A low cost secure element based on a single wire protocol (SWP) interface is also described in the document and proposed for further prototyping stage.

This task proposed a new low cost, low power and power efficient mechanism for device pairing under the form of a new secure element able to fulfill the different requirements related to the security of constrained devices directly and indirectly connected to a LTE/LTE-M network. This secure element is built upon two main blocks, the M2M Identity Module (MIM) that takes care of the security function and a configurable bridge that enables easy integration into M2M device designs supporting a collection of widely used interfaces (UART, SPI, I2C, etc).

A software development kit that enables interfacing M2M applications with the secure element was produced.

Task 6.4 includes the chip definition and design stages as well as a chip prototyping stage.

3.5.5 Summary of Technical Achievements

- A network structure for devices connected to a capillary network that achieves better energy efficiency at network level through energy equalization.
- Two complementary and energy efficient MAC algorithms.
- A M2M duty cycling mechanism for LTE/LTE-M capable M2M devices that is “harmless” for legacy users and enables M2M traffic regulation.
- Fully tickless Linux OS and interruption filtering
- A device self-diagnostic framework that also enables optimized network status monitoring.
- A secure element optimized for constrained M2M devices.

3.6 WP7

WP7 is the convergence point of all technical work packages (WPs). It aims to develop Proof of Concepts (PoC) by integrating key concepts and algorithms from WP2 through WP6. The main purpose of these PoCs is to validate selected algorithms by assessing performances and coverage of technical requirements needed in various use cases.

3.6.1 Overall Progress of WP7

WP7 comprises 3 tasks: Task 7.1 focused on selection of use cases defined in WP2 along with most important concepts, algorithms and technologies developed in WP3 through WP6. Task 7.2 aims to fully define testbeds building blocks and integration aspects. Task 7.3 is dedicated to validation of testbeds.

As the result of efforts undertaken within these tasks, the following public deliverables have been produced:

- D7.1 [9] defines 3 testbeds (LTE-M, E2E connectivity and device management) leveraging most valuable algorithms identified in WP3 through WP6. Major scenarios defined in WP2 are selected and represented by these testbeds. Architecture, functionalities, building blocks and interfaces are presented.
- D7.2 [10] details components, interfaces, functionalities and algorithms for each subtestbed along with the tracing of technical requirements.
- D7.3 [11] reveals performance measurement and verification procedures.

In addition to the aforementioned public reports, most important testbed achievements are summarized below.

3.6.2 LTE-M testbed

This testbed is dedicated for the LTE-M air interface. It consists of lab equipment that emulates the PHY layer uplink with two candidate LTE-M algorithms, namely General Frequency Division Multiplexing (GFDM) and Code Division Multiple Access (CDMA). A physical LTE-M radio signal can be sent over the air.

This testbed provides the proof that LTE-M can coexist with LTE in the same frequency band. This assessment was performed using a transmission scenario involving two LTE UEs and one LTE-M device. It can be shown firstly that superimposed LTE and LTE-M signals can be separated from each other and decoded successfully and secondly that the performance of the LTE UEs is not affected at all. As the same receiver is utilized for both communication systems, thus the intended reusability of hardware is demonstrated. These findings confirm the theoretical results from WP3.

A second measurement scenario without the two LTE UEs primarily aimed at the verification of the spectral properties of GFDM. This was shown by a comparison of the measured spectral power density with a respective simulation. Moreover, the required overall QoS concept was evaluated. The BER depending on the SNR was determined using GFDM and compared against simulation results. It was further shown that CDMA-overlay Tx vectors representing different settings of modulation scheme, spreading factor, and transport block size can be successfully decoded. Again, a reasonable match between results from WP3 and the measurement campaign is claimed.

3.6.3 End-to-End communication testbed

This testbed implements selected novelties developed in three main fields:

- Concepts developed within capillary networks
- End-to-end connectivity between M2M devices, not only belonging to the same capillary network, but also from different ones connected to the LTE/LTE-M network
- End-to-end security between M2M devices and M2M server

In order to address various use cases, this testbed can be seen as a composition of five subtestbeds each one based on its capillary network. This represents the real-life sub-networks each one addressing a set of requirements for the end user.

3.6.3.1 Extended E2E connectivity with Capillary-to-Capillary-to-Infrastructure

This subtestbed reflects a scenario in which an ambulance transmits patient vital data to hospital over a V2V2I communication type. It demonstrates the feasibility of capillary-to-capillary-to-Infrastructure IP communications. It makes use of an eHealth application as a proof of concept. The architecture is connected through an IPv6 networking technology involving two neighbouring M2M gateways where only one is connected to the infrastructure. The leaf M2M Gateway relies on its neighbour for accessing the M2M services provided by the M2M application domain.

The following techniques have been implemented in this testbed to demonstrate the addressing scalability, heterogeneity, E2E IPv6 connectivity and mobility features.

- Vehicle Identification Number (VIN) based IPv6 addressing
- IPv6 prefix delegation over Neighbor Discovery Protocol (NDP)
- Network mobility support using MIPv6/NEMO
- Extended E2E connectivity scenario

Moreover, the following KPIs have been measured:

- Throughput. This KPI determines the limits of the V2V2I system in terms of technical bottlenecks. In particular, it can be shown that Capillary-to-Infrastructure model can be extended (with limited additional effort) to the pattern Capillary-to-Capillary-to-Infrastructure. This extension (hybridation) allows supporting an additional M2M capillary network through one LTE-M infrastructure connection, which scales up the number of supported devices.
- Number of addresses mapped. VIN-based generated addresses enables the addressing of a total 2^{16} (65536) distinct devices in the capillary network.
- Payload Size. The efficiency of the control plane and the overall overhead generated has been evaluated. The NDP extension Prefix Delegation (ND-PD) is compared to the DHCPv6-PD extension,

which is specified as the next IPv6 prefix delegation standard for LTE-R8. Besides the fact that the number of messages can be reduced, the latency is enhanced.

- Energy per message. For the extended vehicular use case, involving the eHealth scenario, the energy spent on sending a message from an eHealth end device through the Android Cluster Head is measured.

The extended capillary technique reflects early stages of EXALTED solutions deployment during which an M2M gateway may be disconnected from the infrastructure, may not be LTE-M enabled, or experience better QoS through neighbouring M2M gateway. On the long-term, this setting should enable gradual integration of other sorts of machine-type networks and allow them accessing LTE-M services through a heterogeneous ad-hoc radio access.

3.6.3.2 E2E connectivity with data aggregation

This subtestbed implements several key algorithms: adaptive data scaling, weighted fair aggregation, similarity avoidance approximation, and faulty detection and recovery. These algorithms are suited for environmental monitoring use cases in which the following M2M data aggregation treatments are applied in the gateway:

- Adaptively adjusts different offset and amplitudes as measured from environmental sensors (e.g. temperature, humidity, CO₂, etc) and scales them into a unified scale via performing normalization amongst all streams before data aggregation.
- Reduce the complexity in both dimensionality and numerosity, in that only key data are selected for data aggregation
- Provide reliability by intelligently detecting wrong data reported from faulty device and prevent those data from being considered in the aggregation algorithm.
- Preserves good accuracy level with significant complexity reduction and processing speed improvement.

The intelligent gateway is able to heterogeneously collect data from various sensors operating within mismatching types of wireless technologies. Collected data is then aggregated using the aforementioned algorithms prior sending to the application server. It can be shown that the amount of aggregated sensor data transmitted (transmission payload size) over the LTE-M link to the application server represents only 3.75% of the original sensor data (actual payload size) being collected at the gateway. This contributes to enhance the spectrum efficiency thus increasing the scalability of the system. The application server uses the counterpart algorithm to decode in order to recover the original sensor data. The gateway is able to achieve payload size reduction in the dimension of both time and amplitude.

3.6.3.3 E2E connectivity for low power devices

This subtestbed exhibits a logistic monitoring scenario which consists in monitoring drug stock levels in hospitals using low power devices. The principle consists in attaching an NFC tag to medicines. Whenever the medicine package is empty, it is put into a box containing an NFC reader. Upon detecting the NFC tag, the box informs a central server that the health care department is running short of that particular medicine.

A lightweight address translation scheme has been implemented at the M2M gateway, which interconnects low power devices to the IP world. Seamless connectivity can be shown for constrained low power devices. Moreover, the following KPIs have been assessed:

- Number of addresses mapped. Although theoretically the proposed lightweight address translation is able to support up to 65536 nodes behind a single gateway, there is limitation in a real world implementation.
- Transmission payload size. Measurements performed on different encoding strategies. The payload reduction rate could be achieved up to 80%.
- Consumed energy per message has been measured for Zigbee devices sending various chunk sizes of data.

This implemented solution is currently being deployed in several hospitals in Spain.

3.6.3.4 E2E security

This subtestbed emulates a SMM use case which consists in monitoring a solar farm. Energy service provider needs to remotely read the amount of electricity produced by solar panels in the farm. The service provider may want to send commands to solar panels, such as start or stop the production. For various reasons the server may ask some devices to stop generating electricity, either because the electric network is near overloading or because of security reasons like a fire alarm in the installation and so no more electricity must be produced. When the alert is dismissed, the server may resume the production.

The security requirement is the data integrity. A low power Secure Element (SE) has been integrated in this subtestbed and served to prevent the upstream and downstream data from being tampered.

Cryptography performances and KPI related to the computational energy consumption of the SE have been measured for a couple of operational figures. Compared to a smart card, the SE operates 3 times faster to cypher/decipher a message while consuming 44% less power.

3.6.3.5 Offloading capillary network traffic

This new subtestbed has been introduced during the last phase of the project. While the subtestbed described in 3.6.3.2 aims to reduce traffic load at the LTE-M link, this solution can reduce traffic load both at the capillary network and at the LTE-M main link. This algorithm is suitable for SMM use cases in which the sensor signals being monitored are highly compressible. The sensor collects N samples of $\mathbf{x}$ signal, the vector $\mathbf{x}$ is then compressed onto L samples, where $L \ll N$, prior transmitting to the M2M Gateway. Depending on the use case, either the M2M GW sends the information to the application server for decompression or recovers $\mathbf{x}$ by itself.

The following 3 KPIs have been measured:

- Actual payload size. In the subtestbed, 64 samples collected by the sensor are compressed onto 32 samples for transmission. The traffic is thus offloaded by 34,37% at the capillary network.
- Distortion. Mean Square Error (MSE) varies highly depending on the use case. MSE around 10^{-2} has been measured when compressing solar panel samples during several days while monitoring temperature every minute yields a rate around 10^{-6}
- Radio energy consumption is comparable to those obtained in 3.6.3.3 as these subtestbeds share the same software and hardware framework.

3.6.4 Device Management (DM) testbed

This testbed validates novelties in the field of device management. Considered aspects in the three subtestbeds are the lightweight device management message encoding and a novel self-diagnostic for reliability and monitoring.

3.6.4.1 ELFOMA - Lightweight DM

This subtestbed emulates a SMM use case by providing a novel procedure to electricity supplier to avoid importing electricity from abroad or starting a fossil fuelled thermal power plant, in case of energy consumption peaks. Depending on the use case, the gateway may read meter indexes and heater actuators status on a regular basis then post the reading to the application server over the DM protocol. On the downstream, the application server may send commands to the gateway over the DM protocol. Commands, such as read meter, turn on/off heater, are translated by the gateway prior being forwarded to the targeted sensor devices. Having this mechanism, electricity provider can control the overall energy consumption level across the energy distribution network. Turning heaters off for 15 min on a round robin basis would not affect the comfort level in houses.

As LTE-M is a system co-existing with LTE in the same spectrum, the amount of available radio resources for M2M is limited. Therefore device management (DM) control and data flows exchanged over LTE-M must not be verbose. Only standardized protocols are considered in WP4. The first DM solution, namely ELFOMA (Exalted Lightweight DM For OMA-DM v1.x), enables operators to save cost by reusing existing OMA-DM v1.x servers to incrementally manage new constrained M2M devices. Operators not relying on existing OMA-DM server can use the second DM solution which is based on CoAP.

This subtestbed aims to evaluate performances of ELFOMA against OMA-DM. 3 KPIs have been measured (i) Transmission payload size, (ii) Actual payload size, (iii) resources consumption, yielding the following outcomes:

- With the proposed ELFOMA DM solution, stakeholders can reuse their existing OMA-DM v1.x servers to manage constrained M2M devices. Compared to the standard OMA-DM protocol and for a given bandwidth, the number of devices communicating simultaneously over the radio access network can be scaled up by a factor of 9.
- The average size of an ELFOMA message is 100 bytes. Thus messages can be exchanged over a low latency radio access network, i.e. LTE-M, within a reasonable timeframe.
- ELFOMA is 3.3 times less CPU demanding to parse than OMA-DM. We could assume that devices implementing ELFOMA are consuming 3 times less energy to parse DM payloads. The CPU processing capability of devices can be downsized to save device cost.
- ELFOMA is 22.7 times less memory demanding to parse than OMA-DM. The device cost could thus be further lowered.

3.6.4.2 Self-Diagnostic

This subtestbed is oriented towards use cases, such as ITS and SMM, that require as few human attendance as possible. The covered scenarios are root failure cause detection and assisted self-healing.

Besides enhancing the reliability of the M2M devices per se, the purpose of the self-diagnostic feature is to enable the device to collect autonomously as much relevant data as possible on its operational status before reporting these data to a management module. In order to minimize the number of transactions that would occur on a resource constrained radio access network, i.e. LTE-M, the device ought to process these data first to extract the most meaningful information. This is the purpose of the self-diagnostic rule engine running in the device.

Therefore, an appropriate performance measure is given by the KPI: Frequency of queries from the Device Management server to the M2M device. It can be shown that only one query is necessary per diagnosed component.

3.6.5 Summary of Technical Achievements

- Novel algorithms have been selected and integrated onto 8 proof of concepts covering different use cases: ITS, eHealth and SMM.
- Technical requirements have been traced and fulfilled per proof of concepts basis
- Subtestbeds enabled the measurement of 20 Key Performance Indicators (KPIs)
- Concept and algorithms developed with EXALTED satisfy various use cases and actually contribute to:
 - Increase the scalability of the system:
 - Improve the energy efficiency
 - Lower the cost of devices

4. Project Impacts

Finally, EXALTED standardization and dissemination activities have been very active during the life time of the project and are as summarized below.

Patents: 14 patents have been filed.

Standardization Activities: 48 contributions have been made to standardization bodies (3GPP, ETSI, and IETF).

Conference and Workshop Papers: 53 papers have been published or accepted.

Journal and Magazines: 10 articles have been published or accepted.

Book Chapter: 1 book chapter has been produced.

Presentations: 16 presentations have been made at scientific and technical events and other project meetings.

Workshops: 3 international workshops namely International Workshop on Machine-to-Machine Communications (IWM2M) in IEEE GLOBECOM 2011, Internet-of-Things – Enabling Technologies (IoT-ET) in IEEE WCNC 2012 and IWM2M in IEEE GLOBECOM 2012 have been very successfully organized with numerous participants.

Summer School: Successful organization of EXALTED's Training School in collaboration with other EC-funded projects.

Other activities: Edition of 2 journal special issues and a Project booth in Future Network and Mobile Summit 2012.

5. Project Website

The EXALTED portal (<http://www.ict-exalted.eu>) represents one of the main media for dissemination of the project's activities toward specialized public and non-technical or general readers. All public deliverables are available for download.

Project Website: <http://www.ict-exalted.eu>

6. References

- [1] FP7 EXALTED consortium, “D3.1 – First report on LTE-M algorithms and procedures,” project report, version 2.0, Jan. 2012.
- [2] FP7 EXALTED consortium, “D3.2 – Study of commonalities and synergies between LTE-M and the heterogeneous network,” project report, Aug. 2011.
- [3] FP7 EXALTED consortium, “D3.3 – Final report on LTE-M algorithms and procedures,” project report, July. 2012.
- [4] FP7 EXALTED consortium, “D3.4 – LTE-M performance evaluation,” project report, Jan. 2013.
- [5] 3GPP, “TR 36.888 – Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE,” Rel.11, Jun. 2012
- [6] FP7 EXALTED WP6 D6.2 - “Final specification of the energy efficiency implementation”
- [7] FP7 EXALTED WP6 D6.3 - “Final specification of the reliable device implementation”
- [8] http://www.supelec.fr/fi/c_844404/tel-4-des-communications-machine-a-machine-a-l-internet-des-objets.html
- [9] FP7 EXALTED consortium, “D7.1 – Selection of scenarios for proof of concept testbeds and specifications for key building blocks, functionalities and interfaces,” project report, August 2011.
- [10] FP7 EXALTED consortium, “D7.2 – Integration of selected algorithms into platforms and interfaces finalization,” project report, August 2012.
- [11] FP7 EXALTED consortium, “D7.3 – Final proof of concept validation results and analysis,” project report, February 2013.

List of Acronyms

Acronym	Meaning
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
6LoWPAN	IPv6 over Low power Wireless Personal Area Network
API	Application Programming Interface
ARO	Address Registration Option
ARQ	Automatic Repeat-reQuest
AT	Attention
AUTOCONF	Ad-Hoc Network Autoconfiguration
BARG	Billing and Accounting Roaming Group
BeFEMTO	Evolved FEMTO Networks
BoF	Birds of a Feather
C2POWER	Cognitive radio and Cooperative strategies for POWER saving in multi-standard wireless devices
CDMA	Code Division Multiple Access
CHOSEN	Cooperative Hybrid Objects in SEnsor Networks
CoAP	Constrained Application Protocol
CoRE	Constrained RESTful Environments
CR	Change Request (e.g. to a 3GPP or ETSI document)
CR	Cognitive Radio
CSIM	CDMA SIM
CT	Core network & Terminals
DECT	Digital Enhanced Cordless Telecommunications
DHC	Dynamic Host Configuration
DHCP	Dynamic Host Configuration Protocol
DM	Device Management
DySPAN-SC	Dynamic Spectrum Access Networks Standards Committee
EARTH	Energy Aware Radio and neTwork tecHnologies
EC	European Commission
EMC	IEEE Electromagnetic Compatibility Society
eNB	E-UTRAN Node B

ESMIG	European Smart Metering Industry Group
ETSI	European Telecommunications Standards Institute
eUICC	Embedded Universal Integrated Chip Card
EURASIP	European Association for Signal Processing
EXALTED	EXpanding LTE for Devices
HSPA	High Speed Packet Access
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IPv6	IP version 6
GBA	Generic Bootstrapping Architecture
GENESI	Green sEnsor NETworks for Structural monItoring
GHC	Generic Header Compression
GINSENG	Performance control in wireless sensor networks
GSM	Global System for Mobile Communications
GSMA	GSM Association
GPRS	General Packet Radio Service
HA	Home Agent
HTTP	HyperText Transfer Protocol
LOLA	Achieving LOw-LAtency in Wireless Communications
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LTE-M	LTE for Machines
LWIG	Light-Weight Implementation Guidance
M2M	Machine-to-Machine
MAC	Medium Access Control
MEXT	Mobility EXTension for IPv6
MFF	M2M Form Factor
MIF	Multiple InterFace
MIP	Mobile IPv6 Protocol
MME	Mobility Management Entity
MNO	Mobile Network Operator
MTC	Machine Type Communications
MVN	Mobile Virtual Network
NAS	Non Access Stratum
NEWCOM++	Excellence in wireless Communications++
NIMTC	Network Improvements for Machine Type Communications
NGMN	Next Generation Mobile Networks
OEM	Original Equipment Manufacturer
OMA	Open Mobile Alliance
OSA	Open Standards Alliance
OTA	Over-The-Air
P-GW	Packet data network GateWay
PHY	Physical Layer
PKI	Public Key Infrastructure
RAN	Radio Access Network
RAS	Radio Access Spectrum
REQ	Requirements
REST	Representational State Transfer
RFC	Request For Comments
ROLL	Routing Over Low power and Lossy networks
RP	RAN Plenary
RPL	Routing Protocol for Low power and lossy networks

RRC	Radio Resource Control
RRS	Reconfigurable Radio System
S-GW	Serving GateWay
SA	System Aspects
SAS	Security Assessment Scheme
SCAG	Smart Card Application Group
SCC	Standards Coordinating Committee
SCP	Smart Card Platform
SID	Study Item Description
SIM	Subscriber Identity Module
SIMTC	System Improvements for Machine Type Communications
SME	Small and Medium Enterprises
SMS	Short Message Service
SUPELEC	Ecole SUPérieure d'ÉLECtricité
TC	Technical Committee
TCCC	Technical Committee on Computer Communications
Tdoc	Temporary document
TEC	Technical
TR	Technical Report
TS	Technical Specification
TSG	Technical Specification Group
TSG-SA	Technical Specification Group System Aspects
TSG-RAN	Technical Specification Group Radio Access Network
UE	User Equipment
UICC	Universal Integrated Chip Card
UMTS	Universal Mobile Telecommunications System
URI	Universal Resource Identifiers
USIM	Universal SIM
VITRO	Virtualized dIstributed plaTfoRms of smart Objects
WG	Working Group
WP	Work package
WWRF	Wireless World Research Forum

7. Use and Dissemination of Foreground

7.1 Section A

This section describes the dissemination measures, including any scientific publications relating to foreground. Its contents is available to the public domain.

7.1.1 Standardization activities

Some of the concepts of EXALTED proposed by EXALTED partners have been discussed and/or accepted to include in the specification by 3GPP, ETSI and IETF. As the standardization process for MTC is still on-going within many of these bodies some of the ideas conceptualised in EXALTED may be adopted in the future by the standards bodies.

Overall, 48 standards contributions with a direct mapping to EXALTED were carried out.

3GPP: 33 contributions

- 1) "M2M Specific Optimisations for LTE", Vodafone (VGSL), Gemalto (GTO), Sierra Wireless (SW), S1-110139, 3GPP SA WG1, Nashville, USA, Feb 2011.
- 2) 'MTC device migration from GSM', Vodafone (VGSL), Sagemcom SAS (SC), RP-110419, 3GPP TSG RAN #51, Kansas, USA, March 2011.
- 3) 'LS to ETSI M2M on potential co-operation between 3GPP work on MTC security and ETSI M2M', Vodafone (VGSL), S3-110558, 3GPP SA3#63, Chengdu, April 2011.
- 4) 'Merits of the Slotted Access Methods for MTC', Alcatel-Lucent, Alcatel Shanghai Bell (ALUD), R2-112247, 3GPP RAN2 #73bis, Shanghai, April 2011.
- 5) 'Proposed SID: Provision of low cost MTC terminals based on LTE', Vodafone (VGSL), RP-110899, 3GPP TSG RAN #52, Bratislava, Slovakia, May 2011.
- 6) 'M2M: Small data transmission using optimised SMS', Vodafone (VGSL), S2-112899, 3GPP SA WG2 #85, Xi'an, China, May 2011.
- 7) "Further Study of Access Performance for MTC", R2-113183, Alcatel-Lucent (ALUD), Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG2 #74, Barcelona, Spain, May 2011.
- 8) "Draft SID for further work on MTC for prioritized use cases by TSG SA", RP-110912, Nokia Siemens Networks, Nokia Corporation, Alcatel-Lucent (ALUD), MediaTek, 3GPP TSG-RAN #52, Bratislava, Slovakia, June 2011.
- 9) 'Efficient small data transmission', Vodafone (VGSL), IPWireless, S2-113826, 3GPP SA WG2 #86, Naantali, Finland, July 2011.
- 10) "Integrated Slotted Access with EAB for MTC", R2-114391, Alcatel-Lucent (ALUD), Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG2 #75, Athens, Greece, August 2011.
- 11) "Considerations on potential solutions for low-cost MTC UEs", R1-113334, Alcatel-Lucent (ALUD), Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #66bis, Zhuhai, China, Oct 2011.
- 12) "Proposals on RAN1 aspects for study of Low cost MTC device", P.Bhat, Vodafone (VGSL), R1-113443, 3GPP RAN1 #66bis, Zhuhai, China. Oct 2011.
- 13) "Draft skeleton TR proposal "Provision of low-cost MTC UEs based on LTE", P.Bhat, Vodafone (VGSL), R1-113604, 3GPP RAN1 #66bis, Zhuhai, China, Oct 2011.
- 14) "Next steps for Study on Provision of Low-Cost MTC UEs", R1-114068, Alcatel-Lucent (ALUD), Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #67, San Francisco, USA, Nov 2011.

- 15) "Summary of E-mail discussions on MTC application scenarios and evaluation methodology", P.Bhat, Vodafone (VGSL), 3GPP RAN1 #67, SFO, USA, R1-114303, Nov. 2011.
- 16) "Text Proposal for Traffic model/characteristics for MTC", P.Bhat, Vodafone (VGSL), 3GPP RAN1 #67, SFO, USA, R1-114443, Nov. 2011.
- 17) "Support of reduced maximum bandwidth for low-cost MTC UEs", R1-120510, Supporting companies: Alcatel-Lucent (ALUD), Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN1 #68, Dresden, Germany, Feb. 2012.
- 18) "Report of email discussion on TR inputs for "Cost drivers of reference LTE modem", P.Bhat, Vodafone (VGSL), 3GPP RAN1 #68, Dresden, Germany, R1-120795, Feb. 2012.
- 19) "Text Proposal for section 5.3 of 3GPP TR 36.888", P.Bhat, Vodafone (VGSL), R1-120925, 3GPP RAN1 #68, Dresden, Germany, Feb. 2012.
- 20) "Views on Cost reduction techniques for "Low cost MTC UE based on LTE", ", P.Bhat, Vodafone (VGSL), R1-120797, 3GPP RAN1 #68, Dresden, Germany, Feb. 2012.
- 21) TR 36.888 v1.0.0, P.Bhat, Vodafone (VGSL), RP-120270, 3GPP RAN #55, Xiamen, China, Feb. 2012.
- 22) "Text proposal for TR 36.888 on restriction of techniques to low performance MTC UEs", P.Bhat (VGSL), E.Hardouin (Orange), R1-121720, 3GPP RAN1 #68bis, Jeju, S.Korea, Mar. 2012.
- 23) "Updated TR 36.888", P.Bhat, Vodafone (VGSL), R1-120891, 3GPP RAN1 #68, Dresden, Germany, Feb. 2012.
- 24) "On single receive RF chain for low-cost MTC UEs", R1-121255, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #68bis, Jeju, Korea, March 2012.
- 25) "On reduction of maximum transmit power for low-cost MTC UEs", R1-121256, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #68bis, Jeju, Korea, March 2012. "On half duplex operation for low-cost MTC UEs", R1-121257, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #68bis, Jeju, Korea, March 2012.
- 26) "On half duplex operation for low-cost MTC UEs", R1-121257, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #68bis, Jeju, Korea, March 2012
- 27) 3GPP TR 36.888 to include agreements from RAN1#69, P.Bhat, Vodafone (VGSL), R1-123075, 3GPP RAN1 #69, Prague, Czech Republic, May 2012.
- 28) "Text Proposal on some aspects of section 9 of 3GPP TR 36.888", P.Bhat, Vodafone (VGSL), R1-123074, 3GPP RAN1 #69, Prague, Czech Republic, May 2012.
- 29) "E-mail discussion summary for TP to clause 7 of 3GPP TR 36.888", P.Bhat, Vodafone (VGSL), R1-123072, 3GPP RAN1 #69, Prague, Czech Republic, May 2012.
- 30) "Text Proposal for clause 7 of 3GPP TR 36.888", P.Bhat, Vodafone (VGSL), R1-123073, 3GPP RAN1 #69, Prague, Czech Republic, May 2012.
- 31) "SI conclusion for low cost MTC UEs", Multiple Authors, ALUD, R1-122505, 3GPP TSG RAN WG1 #69, Prague, Czech Republic, May 2012.
- 32) "Feasibility of coverage extension of physical channels for MTC devices", R1-130462, Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #72, St. Julians, Malta, Jan. 2013.
- 33) "Channel characteristics and channel estimation for extended coverage MTC", R1-130463, Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, 3GPP TSG RAN WG1 #72, St. Julians, Malta, Jan. 2013.

ETSI & GSMA: 11 contributions

- 1) 'Proposed WID: Use cases and requirements related to Embedded UICCs', AT&T, Gemalto, Sagem Orga, et al, SCP (11)0146r1, ETSI SCP REQ #29, Sophia Antipolis, March 2011.
- 2) 'Embedded SIM Task Force Requirements and Use Cases', GSMA, SCP (11)0088, ETSI SCP REQ #29, Sophia Antipolis, March 2011.
- 3) 'Liaison Statement on new Work Item for eUICC - to 3GPP and 3GPP/2', ETSI TC SCP, SCP (11)0147r1, ETSI SCP REQ #29, Sophia Antipolis, March 2011.

- 4) 'CR against TS_102_412, "Addition of requirements for the eUICC', Deutsche Telekom, Giesecke & Devrient, Telefonica O2, Vodafone, SCPREQ (11)0043 , ETSI SCP REC ad hoc #113, London, UK, April 2011.
- 5) 'Discussion document on definitions pertaining to Embedded UICC', Deutsche Telekom, Telefonica O2, Vodafone, Giesecke & Devrient, SCPREQ (11)0044 , ETSI SCP REC ad hoc #113, London, UK, April 2011.
- 6) 'High Level Components in eUICC First_provisioning', Vodafone Group, SCPREQ (11)0064 , ETSI SCP REQ #30, Caserta, Italy, May 2011.
- 7) 'Embedded UICC – A high level remote provisioning architecture', GSMA Embedded SIM Task Force: Technical Stream, SCPREQ (11)0113 , ETSI SCP REQ #32, San Diego, USA, July 2011.
- 8) 'GSMA and SIM alliance Collaboration on eUICC Protection Profile', GSMA, SCPREQ (11)0118 , ETSI SCP REQ #32, San Diego, USA, July 2011.
- 9) "Considerations for addressing End-to-end Security in M2M Release 2", H. Ganem *et al*, ETSI-M2M TC, March 2012.
- 10) "Considerations for addressing dfa Security in M2M Release 2", H. Ganem *et al*, ETSI-M2M TC, March 2012.
- 11) "Method for a harmonized definition of Low Duty Cycle transmission as a passive mitigation technique used by short range devices and conformance test Methods", C. Ibars (CTTC) *et al*, ETSI TS 103 060, ETSI-STF411, Oct. 2012.

IETF: 4 contributions

- 1) "Scenarios and Requirements for IP in Intelligent Transportation Systems", A. Petrescu et al (CEA), draft-petrescu-its-scenarios-reqs-01.txt, Internet-Draft, Network Working Group, CEA, Renault, July 2012.
- 2) "Default Router List Option for DHCPv6 (DRLO)", A. Petrescu, K. Pentikousis, C. Janneteau, M. Mouton (CEA), draft-mouton-mif-dhcpv6-drlo-02, Internet-Draft, Network Working Group, CEA, HUAWEI, September 2012.
- 3) "Prefix Delegation extension to Neighbor Discovery protocol", A. Kaiser, S. Decremps, A. Petrescu (CEA), draft-kaiser-nd-pd-00, Internet Engineering Task Force, 85th edition, Atlanta, November 2012.
- 4) "A Security Framework for Routing over Low Power and Lossy Networks," T. Tsao, R. Alexander, Mischa Dohler, V. Daza, A. Lozano, IETF Requirement Draft for Routing over Low Power and Lossy Networks (ROLL), work in progress.

7.1.2 Publications

In this section we list all publications directly related to EXALTED and authored by members of the EXALTED team. Besides the authors, in each publication we identify the partner institution and in which workpackage of EXALTED the work was carried out.

7.1.2.1 Journals, Magazines, and Books

The following book chapter (1) and ten (10) journal publications have been recently published or have been accepted for publication in the coming months:

1. P. S. Bithas, A. Lioumpas, and A. Alexiou (**UPRC-WP4**), "Mitigating Shadowing Effects Through Cluster-Head Cooperation Techniques," accepted for publication in IET on Networks, Dec 2012.
2. Y. Ma, R. Tafazolli, Z. Lu (**UNIS-WP3**), "Cluster-Based Differential Energy Detection for Spectrum Sensing in Multi-Carrier Systems", To appear in IEEE Transactions on Signal Processing, 2012
3. S. Vural, P. Navaratnam, and R. Tafazolli (**UNIS-WP4**) "Transmission Range Assignment for Backbone Connectivity in Clustered Wireless Networks", To appear in IEEE Wireless Communications Letters, 2012

4. J. Alonso-Zárate, J. Matamoros, D. Gregoratti, Mischa Dohler (**CTTC-WP4**), "Machine-to-machine communications in smart grid", Book Chapter in E. Hossain, Z. Han, H.V. Poor (Edts), "Smart Grid Communications and Networking," Cambridge University Press, 2012.
5. K. Zheng, F. Hu, W. Xiangy, and M. Dohler (**CTTC-WP3**), "Radio Resource Allocation in LTE-Advanced Cellular Networks with M2M Communications", To appear in IEEE Communications Magazine, 2012.
6. J. Alonso-Zárate, C. Crespo, Ch. Skianis, L. Alonso, and Ch. Verikoukis (**CTTC-WP4**), "Distributed Point Coordination Function for IEEE 802.11 Wireless Ad hoc Networks", Elsevier Ad Hoc Networks Journal, May 2012.
7. B. Devillers, D. Gunduz(**CTTC-WP3**), "A General Framework for the Optimization of Energy Harvesting Communication Systems with Battery Imperfections", To appear in Journal of Communications and Networks (JCN)- Special Issue On Energy Harvesting in Wireless Networks, April 2012.
8. D. Wei, Y. Jin, S. Vural, K. Moessner, R. Tafazolli (**UNIS-WP4**), "An Energy-efficient Clustering Solution for Wireless Sensor Networks", IEEE Transactions On Wireless Communications, Vol. 10 , No. 11, Nov. 2011.
9. A. G. Gotsis, A. S. Lioumpas and A. Alexiou (**UPRC-WP3**), " Machine-to-Machine Scheduling over LTE Networks: Challenges and new Perspectives" IEEE Vehicular Technology Magazine, Sep 2012.
10. A. Bartoli, J. Hernández-Serrano, M. Soriano, M. Dohler, A. Kountouris and D. Barthel, (**CTTC-WP4**) "Secure Lossless Aggregation Over Fading & Shadowing Channels For Smart Grid M2M Networks" IEEE Transactions on Smart Grids, Special Issue on Smart Grid Security, vol. 2, no 4., pp. 844-864, June 2011.
11. N. Chu, D. Raouf, B. Corlay, M. Ammary, N. Gligoric, S. Krco, N. Ognjanovic, A. Obradovic (**SWIR,EYU,TKS-WP4**), "OMA-DM v1.x compliant Device Management for Lightweight M2M devices", Trans. on Emerging Telecommunications Technologies, special issue on Machine-to-Machine: An Emerging Communication Paradigm.

In addition, seven (7) more manuscripts were submitted to various journals and are still under review

1. G. Cocco, D. Gunduz and C. Ibars (**CTTC-WP3**), "Streaming over Block-Fading Channels with Delay Constraint", Submitted to IEEE Transactions on Wireless Communications, April 2012.
2. A. G. Gotsis, A. S. Lioumpas and A. Alexiou (**UPRC-WP3**), "Analytical Modeling and Performance Evaluation of Realistic Time-Controlled M2M Scheduling over LTE Cellular Networks" submitted to Transactions on Emerging Telecommunication Technologies, Special Issue on Machine-to-Machine: An Emerging Communication Paradigm, Wiley, 2013.
3. N. Gligoric, T. Dimcic, S. Krco, D. Dragic, N. Chu, A. Obradovic (**EYU-WP3**), "M2M Device Management over Short Message Service (SMS)" submitted to Trans. on Emerging Telecommunications Technologies, special issue on Machine-to-Machine: An Emerging Communication Paradigm.
4. J. Matamoros, C. Anton-Haro (**CTTC-WP4**) "Compressed Spatial Field Estimation with M2M Capillary Networks" Submitted to IEEE Transactions on Wireless Communications.
5. S. Mirzadeh, H. Cruickshank, and R. Tafazolli, (**UNIS-WP4**) "Secure Device Pairing – A Survey" Submitted to IEEE Communication Surveys & Tutorials
6. G. Cocco, C. Ibars, N. Alagha (**CTTC-WP3**) "Coverage extension in heterogeneous satellite machine-to-machine networks" Transactions On Emerging Telecommunications Technologies.
7. Serdar Vural, Pirabakaran Navaratnam, Ning Wang, and Rahim Tafazolli (**UNIS-WP4**) "Asynchronous Clustering of Multihop Wireless Sensor Networks," ACM Transactions on Sensor Networks.

7.1.2.2 Conferences and Workshops

There have been fifty-three (53) contributions presented to, or accepted for, conferences and workshops. Out of them, thirteen (13) papers have been submitted by consortium members to the three workshops organized by the project in conjunction with IEEE-GLOBECOM'11, IEEE-WCNC'12 and IEEE-GLOBECOM'12 respectively.

The following list enumerates papers have been accepted and/or published. In brackets we indicate the institution/institution that the partners belong to, as well as the corresponding Workpackage in EXALTED.

1. G. Cocco, D. Gunduz, C. Ibars (**CTTC-WP3**) "Throughput and Delay Analysis in Video Streaming over Block-Fading Channels" Accepted IEEE International Conference on Communications 2013.
2. J. Matamoros and C. Antón-Haro (**CTTC-WP4**) "Traffic Aggregation Techniques for Environmental Monitoring in M2M Capillary Networks" Accepted IEEE Vehicular Technology Conference (VTC-spring), Dresden
3. C. Qian, H. Chen, Y. Ma and R. Tafazolli, (**UNIS-WP4**) "A Novel Adaptive Hybrid-ARQ Protocol for Machine-to-Machine Communications" Accepted IEEE VTC Spring 2013
4. P. Blasco, D. Gunduz and M. Dohler (**CTTC-WP4**), "A Learning Theoretic Approach to Energy Harvesting Communication System Optimization", Globecom 2012 - Int'l Workshop on Machine-to-Machine Communications, Anaheim (CA), Dec. 2012.
5. M. Grieger, S. Boob, G. Fettweis (**TUD-WP3**), "Large Scale Field Trial Results on Frequency Domain Compression for Uplink Joint Detection", Globecom 2012, Workshop on Multicell Cooperation, Anaheim (CA), Dec. 2012.
6. A. Bartoli, J. Hernández-Serrano, M. Soriano, M. Dohler, A. Kountouris and D. Barthel (**CTTC-WP4**), "Optimizing Energy-Efficiency of PHY-Layer Authentication in Machine-to-Machine Networks", Globecom 2012 - Int'l Workshop on Machine-to-Machine Communications, Anaheim (CA), Dec. 2012.
7. A. G. Gotsis, A. S. Lioumpas, and A. Alexiou (**UPRC-WP3**), "Evolution of Packet Scheduling for Machine-Type Communications over LTE: Algorithmic Design and Performance Analysis", Globecom 2012 - Int'l Workshop on Machine-to-Machine Communications, Anaheim (CA), Dec. 2012.
8. T. Predojević, J. Alonso-Zarate, L. Alonso, and C. Verikoukis (**CTTC-WP4**), "Energy Efficiency Analysis of a Cooperative Scheme for Wireless Local Area Networks", IEEE Global Conference on Communications (GLOBECOM), Anaheim (CA), Dec. 2012.
9. J. Alonso-Zarate, J. Sánchez Recacha, N. Zorba, A. Perez-Neira, and C. Verikoukis (**CTTC-WP4**), "Cooperative Communications: from Theory to Experimental Implementation", IEEE Global Conference on Communications (GLOBECOM), Anaheim (CA), Dec. 2012.
10. F. Vázquez Gallego, J. Alonso-Zarate, and L. Alonso (**CTTC-WP4**), "Energy Analysis of Distributed Neighbour Discovery Algorithms Based on Frame Slotted-ALOHA for Cooperative Networks", IEEE Global Conference on Communications (GLOBECOM 2012), Anaheim (CA), Dec. 2012.
11. P. S. Bithas, A. S. Lioumpas and A. Alexiou (**UPRC-WP4**), "A Hybrid Contention/Reservation Medium Access Protocol for Wireless Sensor Networks", IEEE Globecom 2012 - Int'l Workshop on Machine-to-Machine Comms., Anaheim (CA), Dec. 2012.

12. N. Gligorić, T. Dimčić, D.Drajić, S. Krčo, N. Chu, **(EYU-TKS-SIERRAW, WP4)** "Application-Layer Security Mechanism for M2M communication over SMS", 20th Telecommunications forum (TELFOR 2012), 20-22 November, Belgrade, Serbia
13. "N. Gligorić, T. Dimčić, D.Drajić, S. Krčo, I. Dejanović, N. Chu, A. Obradović" **(EYU-TKS-SIERRAW, WP4)**, "CoAP over SMS Performance Evaluation for Machine to Machine Communication" 20th Telecommunications forum (TELFOR 2012), 20-22 November, Belgrade, Serbia
14. S. Imadali, A. Karanasiouy, A. Petrescu, I. Sifniadis, and V. Vèque (CEA, **VID-WP4,7**), "EHealth Service Support In IPv6 Vehicular Networks", VECON 2012, 2nd Int'l Workshop on Vehicular Communications and Networking (in conjunction with IEEE WiMob 2012), Barcelona (Spain), Oct. 2012.
15. M. R: Palattella, N. Accettura, M. Dohler, L. A. Grieco and G.Boggia (**CTTC-WP4**), "Traffic-Aware Time-Critical Scheduling In Heavily Duty-Cycled IEEE 802.15.4e for an Industrial IoT", IEEE Sensors 2012, Taipei (Taiwan), Oct. 2012.
16. T. Predojević, J. Alonso-Zarate, M. Dohler (**CTTC-WP4**), "Energy Analysis Of Cooperative and Duty-Cycled Systems In Shadowed Environments", IEEE Int'l Conference on Computer Aided Modelling, Design and Analysis (CAMAD'12), Barcelona (Spain), Sep. 2012.
17. J. Rico, B. Cendón (**TST-WP4**), "NFC Enabling Hospital Logistics System, NFC World Congress Conference", Nice - Sophia Antipolis, Sep. 2012.
18. G. Corbellini, C. Abgrall, E. Calvanese Strinati, A. Duda (**CEA-WP4**), "Energy Evaluation of Preamble Sampling MAC Protocols for Wireless Sensor Networks", in Proc. Int'l Conference on Personal Indoor and Mobile Radio Communications (PIMRC 2012), Sydney (Australia), Sep. 2012.
19. G. Corbellini, E. Calvanese Strinati, A. Duda (**CEA-WP4**), "LA-MAC: Low-Latency Asynchronous MAC for Wireless Sensor Networks", Int'l Conference on Personal Indoor and Mobile Radio Communications (PIMRC 2012), Sydney (Australia), Sep. 2012.
20. N. Michailow, S. Krone, M. Lentmaier, G. Fettweis (**TUD-WP3**), "Bit Error Rate Performance of Generalized Frequency Division Multiplexing", Vehicular Technology Conference 2012 (VTC-Fall 2012), Quebec City (Canada), Sep. 2012.
21. J. Matamoros and C. Antón-Haro (**CTTC-WP4**), "Joint Pre-Coder Design and Greedy Power Allocation for Compressed Spatial Field Estimation", in European Signal Processing Conference 2012 (EUSIPCO'12), Bucharest, Aug. 2012.
22. J. Rico, J. Sancho, V. Bataller, J.L. Villarroel, C. Rueda, R. Olmedo, J. Diez (**TST-WP4**), "Cooperative System for Avalanche Rescue", Int'l Conference on Wireless Communications in Unusual and Confined Areas, Clermont-Ferrand – France, Aug. 28-30, 2012.
23. W. Nitzold, M. Lentmaier and G. P. Fettweis (**TUD-WP3**), "Spatially Coupled Protograph-Based LDPC Codes for Incremental Redundancy", in Proc. 7th International Symposium on Turbo Codes & Iterative Information Processing, Sweden, Aug. 2012.
24. J. Matamoros and C. Antón-Haro (**CTTC-WP4**), "Data Aggregation Schemes for Machine-to-Machine Gateways: Interplay with MAC Protocols", in Proc. Future Networks and Mobile Summit 2012. Berlin (Germany), Jul. 4-6, 2012.
25. G. Botter, J. Alonso-Zarate, L. Alonso, F. Granelli, Ch. Verikoukis (**CTTC-WP4**), "Extending the Lifetime of M2M Wireless Networks through Cooperation", In Proc. Workshop on Green

Communications and Networking - Int'l Conference on Communications (ICC 2012), Ottawa (Canada), Jun. 2012.

26. J. Matamoros and C. Antón-Haro (**CTTC-WP4**), "Robust Estimation of Spatial Fields with Compressed Observations and Imperfect Phase Estimation in M2M Capillary Networks", in Proc. EURASIP Cognitive Information Processing Workshop (CIP 2012), Baiona (Spain), May 2012.
27. J. Rico, B. Cendón, J. Valiño (**TST-WP4**), "Bringing IoT to Hospital Logistics Systems", Proc. IEEE Wireless Communications and Networking Conference (WCNC 2012) - Workshop on Internet of Things Enabling Technologies: "Embracing the M2M Communications and Beyond", Paris (France), Apr. 2012.
28. N. Accettura, M. R. Palattella, M. Dohler; L. A. Grieco, G. Boggia (**CTTC-WP4**), "Standardized Power-Efficient & Internet-Enabled Communication Stack for Capillary M2M Networks", Proc. IEEE Wireless Communications and Networking Conference (WCNC 2012) - Workshop on Internet of Things Enabling Technologies: "Embracing the M2M Communications and Beyond", Paris (France), Apr. 2012.
29. G. A. Elkheir, A. Lioumpas, A. Alexiou (**UPRC-WP3**), "Energy Efficient Cooperative Scheduling based on Sleep-Wake Mechanisms", Proc. IEEE Wireless Communications and Networking Conference (WCNC 2012) - Workshop on Internet of Things Enabling Technologies: "Embracing the M2M Communications and Beyond", Paris (France), Apr. 2012.
30. P. S. Bithas, A. S. Lioumpas and A. Alexiou (**UPRC-WP4**), "Enhancing the Efficiency of Cluster-based Networks through MISO Techniques", Proc. IEEE Wireless Communications and Networking Conference (WCNC 2012) - Workshop on Internet of Things Enabling Technologies: "Embracing the M2M Communications and Beyond", Paris (France), Apr. 2012.
31. T. Predojević, J. Alonso-Zarate, M. Dohler (**CTTC-WP4**), "Energy Efficiency of Cooperative ARQ Strategies in Low Power Networks", In Proc. IEEE INFOCOM Workshop on Communications and Control for Sustainable Energy Systems: Green Networking and Smart Grids, Mar. 2012.
32. A. Gotsis, A. S. Lioumpas, A. Alexiou (**UPRC-WP3**), "Challenges and New Perspectives on Machine-to-Machine Scheduling over LTE Networks", 28th meeting of the Wireless World Research forum, Piraeus, Greece, Apr. 2012.
33. P. Bithas, A. S. Lioumpas, A. Alexiou (**UPRC-WP4**), "Enhancing the Performance of Cluster-based Networks through Energy Efficient MISO Techniques", 28th meeting of the Wireless World Research forum, Piraeus, Greece, Apr. 2012.
34. G. A. Elkheir, A. S. Lioumpas and A. Alexiou (**UPRC-WP3**), "Energy Efficient Cooperative Scheduling based on Sleep-Wake Mechanisms", 28th meeting of the Wireless World Research forum, Piraeus, Greece, Apr. 2012.
35. N. Michailow, R. Datta, S. Krone, M. Lentmaier and G. Fettweis (**TUD-WP3**), "Generalized Frequency Division Multiplexing: A Flexible Multi-Carrier Modulation Scheme for 5th Generation Cellular Networks", in Proc. GeMiC 2012: the 7th German Microwave Conference, Ilmenau University of Technology, Germany, Mar. 2012.
36. D. Gunduz and B. Devillers (**CTTC-WP3**), Multi-hop Communication with Energy Harvesting, The Fourth International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP'11), San Juan, Puerto Rico, December 13-16.

37. P. Cheraghi, Yi Ma, Z. Lu, and R. Tafazolli, **(UNIS-WP3)**, "A Novel Low Complexity Differential Energy Detection for Sensing OFDM Sources in Low SNR Environment", Globecom 2011 - IWM2M, Dallas (Tx), Dec, 2011.
38. D. Gunduz and B. Devillers **(CTTC-WP3)**, "Two-hop Communication with Energy Harvesting", The Fourth International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP'11), San Juan, Puerto Rico, Dec. 13-16
39. F. Ganz, P. Barnaghi, F. Carrez, K. Moessner **(UNIS-WP4)**, "A Mediated Gossiping Mechanism for Large-scale Sensor Networks", Globecom 2011 - IWM2M, Dallas (Tx), Dec, 2011.
40. A. Lioumpas, A. Alexiou **(UPRC-WP3)**, "Uplink Scheduling for Machine-to-Machine Communications in LTE-based Cellular Systems", Globecom 2011 - Int'l Workshop on Machine-to-Machine Communications, Houston (Tx), Dec. 2011.
41. J. Matamoros and C. Antón-Haro **(CTTC-WP4)**, "Power Allocation Schemes for Spatial Field Estimation with Compressed Observations in M2M Capillary Networks", Globecom 2011 - Int'l Workshop on Machine-to-Machine Communications, Houston (Tx), Dec. 2011.
42. B. Devillers, D. Gunduz **(CTTC-WP3)**, "Energy Harvesting Communication System with Battery Constraint and Leakage", Globecom 2011 - Int'l Workshop on Machine-to-Machine Communications, Houston (Tx), Dec. 2011.
43. G. Cocco, D. Gunduz, C. Ibars **(CTTC-WP3)**, "Application of different coding schemes for broadcast transmissions", Eighth International Symposium on Wireless Communication Systems, Aachen, Germany, 6th - 9th Nov., 2011.
44. G. Cocco, D. Gunduz, C. Ibars **(CTTC-WP3)**, "Real-time broadcasting over block-fading channels, In Proc. the Eighth International Symposium on Wireless Communication Systems (ISWCS)", Aachen, Germany, 6th - 9th Nov., 2011.
45. N. Gligorić, S. Krčo, D. Drajić, S. Jokić, and B. Jakovljević **(EYU-TKS WP4)** "M2M Device Management in LTE Networks", Science telecommunication forum (TELFOR), Belgrade, Nov. 2011
46. G. Abou Elkheir, A. Lioumpas, A. Alexiou **(UPRC-WP3)**, "Energy Efficient AF Relaying under Error Performance Constraints with Application to M2M Networks", Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Sep. 2011.
47. A. Lioumpas, A. Alexiou, C. Antón-Haro, and P. Navaratnam **(UPRC-CTTC-UNIS-WP2)**, "Expanding LTE for devices: Requirements, Deployment Phases and Target Scenarios", Proc. IEEE/VDE European Wireless Conference (EW'11), April 2011.
48. J. Matamoros and C. Antón-Haro **(CTTC-WP4)**, "Opportunistic Sampling for Random Field Estimation with M2M Capillary Networks", Proc. IEEE/VDE European Wireless Conference (EW'11), April 2011.
49. J. Alonso-Zarate, L. Alonso, and C. Verikoukis, **(CTTC-WP4)** "Improving the Energy-Efficiency of Machine-to-Machine Communications with Cooperative ARQ", Proc. Joint Workshop on Wireless Communication (Paris, France), Dec. 2010.
50. F. Ganz, P. Barnaghi, and F. Carrez, **(UNIS-WP4)** "Context-Aware Management of Sensor Networks", Proc. Fifth International Conference on COMmunication System softWARE and middlewaRE (COMSWARE), Verona (Italy), July 2011.

51. F. Ganz, **(UNIS-WP4)** “Designing Smart Middleware for Wireless Sensor Networks”, The 12th annual Post Graduate Network Symposium on the Convergence of Telecommunications, Networking and Broadcasting, (PGNet2011), Liverpool, April 2011.
52. A. Lioumpas, A. Alexiou, **(UPRC-WP3)** “On the Switching Rate of ST-MIMO Systems with Energy-based Antenna Selection”, Proc. EuCap 2011, Rome, Italy, April 2011.
53. A. Petrescu, M. Boc, C. Ibars, **(CEA-CTTC WP3-4)** “Joint IP Networking and Radio Architecture for Vehicular Networks”, International Conference on ITS Telecommunications (ITST 2011), St Petersburg, August 2011.

In addition, 4 more contributions were submitted to various conferences and workshops and are still under review

1. Hong Chen, Yi Ma and Rahim Tafazolli **(UNIS-WP3)** "Improved Fountain Codes for Short Block Transmission over Noisy Channels " Submitted to IEEE GLOBECOM, Atlanta, USA., December 2013.
2. S. Imadali, A. Karanasiou, A. Petrescu, I. Sifniadis, E. Vellidou, and P. Angelidis **(CEA-VIDAVO, WP7)** "Integration of eHealth Service in IPv6 Vehicular Networks" Submitted to the 3rd Int'l Conference on Ambient Media and Systems (Ambi-sys), Athens, Greece, March 2013.
3. "S. Imadali, A. Petrescu, M. Boc, V. Veque" **(CEA-WP4)** "VULA: VIN-based Unique Local IPv6 Address Auto-configuration for VANET" Submitted to IEEE WoWMoM 2013.
4. J. Rico, J. Valiño, E. Epifanio **(TST-WP4)** "Cluster Head Assignment in Networks controlled by Gateway Entities (CHANGE)" Submitted to First International WorkShop on Energy-Aware Systems, Communications and Security (EASyCoSe 2013), to be held in conjunction with the 27th IEEE International Conference on Advanced Information Networking and Applications (AINA-2013), Barcelona, Spain, March 2013.

7.1.2.3 Presentations in Scientific and Technological Events

The dissemination activities conducted by EXALTED partners also encompassed the following presentations in various S&T events, namely,

1. B. Corlay, C. Anton-Haro, A. Petrescu, “Expanding LTE for devices,” **ETSI M2M Workshop**, Sofia-Antipolis (Nice), October 2010.
2. D. Raouf, “New Scalable Network Architecture for M2M Communications: The ‘EXALTED’ approach”, **WWRF25 meeting**, Newbury (UK), Nov. 2010.
3. J. Alonso, “Machine-to-Machine: An Emerging Communication Paradigm”, **WWRF25 meeting**, Newbury (UK), Nov. 2010.
4. S. Saur, “General overview of EXALTED”, **Joint ALUD and Heinrich-Hertz-Institute (HHI) M2M Workshop** in Berlin (ALUD), Dec. 2010.
5. D. Raouf, Project presentation at **FUTURE NETWORKS concertation meeting**, Feb. 2011.
6. C. Antón-Haro, Project presentation in **NEWCOM++ Smart Grids Workshop**, Feb. 2011.
7. Srdjan Krc, “EXALTED overview”, **Ericsson Research seminar**, Kista, Sweden, May 2011.
8. Thierry Lestable (SC), Smart Energy Management “From Innovation to Deployment”, M2M conference: M2M standards as growth enablers - **TIA** (Atlanta), Sept. 2011.

9. W. Nitzold (TUD), Poster Session within the Industrial Partner Program at TU Dresden, Presenting EXALTED within the **Industry Partnership Program at TU Dresden**, Sept. 2011.
10. A. Alexiou (UPRC) , “M2M Communications”, **ITU Academy Workshop**. Athens (Greece). March 2012.
11. C. Ibars (CTTC), “M2M Communications”, **LTE World Summit**, Barcelona, May 2012.
12. T. Lestable (SC), “EXALTED project”, **General Assembly of the ICT-LOLA project**, May 2012, Paris.
13. A. Alexiou (UPRC), “M2M communications - Technology trends and research challenges”, **Future Networks and Mobile Summit** (in the context of a WWRF-organised workshop), July 2012. Sept. 2012.
14. N. Ognjanovic, D. Drajić, S. Saur, “EXALTED achievements” at **M2M Workshop at University of Siegen**, Feb. 2013.
15. D. Raouf, “EXALTED Preliminary Results”, **RAS Cluster – 10th Concertation Meeting**, October 2012
16. D. Raouf, “EXALTED Preliminary Results”, 4G and Beyond, **Supélec** – Gif-sur-Yvette, November 2012.

7.1.2.4 Journal Special Issues and Training School

EXALTED project partners have also engaged in the organization of one Journal Special Issue in Wiley’s Transactions on Emerging Telecommunications Technologies (ETT), and one Journal Special Issue in IEEE’s Communications Surveys & Tutorials. The special issues are aimed at enlarging the project’s footprint in the scientific community

EXALTED’s training school was organized in cooperation with other EC funded projects, namely, LOLA, Smart Santander, HOBNET and IoT6 in the context of senZations training school in Mecavnik (Serbia). The senZations training school, now in its seventh edition, has become an annual event on the agenda of young researcher talents across Europe and other parts of the world. It covers in depth a range of advanced topics from wireless sensor networks to M2M to Internet of Things, as well as their applications.

Moreover, members of the EXALTED project team have organized Journal Special Issues, tutorials at IEEE ICC and Globecom, among others, participated and chaired technical committees, and given keynote speeches, all these in the topic of M2M, and directly reporting results from the Project.

7.1.2.5 Workshops

The first EXALTED International Workshop on Machine-to-Machine Communications (IWM2M) took place in the IEEE Global Communications Conference (Globecom) in Houston, Texas, on December 9th, 2011. The organizing committee included members from several EXALTED partners, and the TPC included worldwide experts from both academia and industry. The technical program featured topics of high relevance, such as networks, resource allocation, energy efficiency, as well as technical and business challenges. A second edition of the successful IWM2M took place in IEEE Global Communications Conference (Globecom) in Anaheim, CA, USA, on December 7th, 2012. Besides the IWM2M, an international workshop entitled Internet of Things Enabling Technologies: “Embracing the M2M Communications and Beyond” took place at the IEEE Wireless Communications and Networking Conference (WCNC) on April 1st, 2012 in Paris. The

workshop organizing committee also included members from several EXALTED partners. Four technical sessions, in the topics of Smart Grid and RFID Technologies, M2M Network Architecture, Application and Experiment, and Energy Efficiency, were included.

7.2 Section B

The content of the two following section 7.2.1 and 7.2.2 are confidential unless stated otherwise.

7.2.1 Patents

The following patents were filed by EXALTED partners, related to the technical developments in EXALTED

1. Method for reduced resource usage in system synchronization, Inventors: G. Fettweis, W. Nitzold, S. Krone, T. Gill, 11176361, Filed, Applicant: TUD (assigned to Vodafone), European Patent, Aug. 2011.
2. Method for reduced resource usage in system synchronization, Inventors: G. Fettweis, W. Nitzold, S. Krone, T. Gill, 13/565,029, Filed, Applicant: TUD (assigned to Vodafone), US Patent, Aug. 2011.
3. Method for minimizing the collision of multicast acknowledgments, Inventors: G. Fettweis, W. Nitzold, S. Krone, T. Gil, 11180527, Filed, Applicant: TUD (assigned to Vodafone), European Patent, Sep 2011.
4. Secondary wireless communication terminal integration, Inventors: G. Fettweis, P. Rost, W. Nitzold, 10168318.3, Applicant: TUD, (assigned to Vodafone), European Patent, 2010.
5. Dispositif et Procédé pour Generer une Adresse Internet Protocol (IP) a Partir d'un Numero d'Identification de Vehicule (VIN), Inventors: S. Imadai, A. Petrescu, C. Janneteau, 12/56772, Applicant: CEA, French Patent, July 2012.
6. Système de communication entre un équipement non connecté et un serveur de gestion, Inventors: Nhon Chu, Djelal Raouf, Applicant: Sagemcom, French Patent, Sept. 2011.
7. Procédé de contrôle de l'accès d'un équipement pour réseau de type machine-à-machine aux ressources d'un réseau de téléphonie cellulaire, Inventors: Bruno Corlay, Djelal Raouf, Applicant: Sagemcom, French Patent, Febr. 2012.
8. WO2012085593: SIM Locking ; filed June 28, 2012; BABBAGE, Steven BONE, Nicholas; VODAFONE IP LICENSING LIMITED
9. WO2012080740, KEY DERIVATION; filed June 21 2012; BABBAGE, Steven BONE, Nicholas; VODAFONE IP LICENSING LIMITED
10. WO2012076437 : IMPROVEMENTS TO UICCs EMBEDDED IN TERMINALS OR REMOVABLE THERE FROM :file 17/08/2012 MERRIEN Lionel,MATHIAN Nicolas,ROUSSEL, Nicolas,BERARD, Xavier,GACHON, Denis,GIRARD Pierre,PROUST Philippe,VERGNES Fabrice,FARIA Frédéric , IMOUCHA Franck,BRADLEY Paul ; GEMALTO SA
11. WO2012076461 : METHOD FOR SWITCHING BETWEEN A FIRST AND A SECOND LOGICAL UICCS COMPRISED IN A SAME PHYSICAL UICC; filed 05/12/2011 VERGNES Fabrice , MATHIAN Nicolas; GEMALTO SA
12. WO2012035338 : AUTHENTICATION IN A WIRELESS ACCESS NETWORK; filed 22/03/2012 BONE, Nicholas;HOWARD, Peter; VODAFONE IP LICENSING LIMITED
13. WO2012035335: AUTHENTICATION IN A WIRELESS TELECOMMUNICATIONS NETWORK; filed 22/03/2102 ;BONE, Nicholas; VODAFONE IP LICENSING LIMITED
14. Procédé de transmission d'un message d'urgence entre un véhicule et un centre d'appel, Inventors: Djelal Raouf, Jérémie Dumont, Nhon Chu; Applicant: Sagemcom, French Patent, March 2012.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	The University of Surrey, being a higher-education institute with a strong focus on research and innovation, intends to exploit its participation in the EXALTED project by exposing post-graduate researchers to high-quality deployable technical work thus training future researchers and engineers strengthening the future European workforce. The acquired knowledge will be widely disseminated through publications in journals and conferences and through the participation in trials and demonstrations. This knowledge will also be used to enrich the material of relevant MSc courses, and will be used to enhance the content of tutorials presented in major international conferences/workshops and relevant industry short-courses. The final aim is to use the outcomes of EXALTED as basis for future scientific endeavours.	NO	Not applicable	LTE-M system concepts	1. Scientific research and development	2011	None	UNIS
				Advancements in M2M networks	2. Higher education	2013		
General advancement of knowledge	New advances in communications protocols and algorithms for energy and cost constrained LTE-like devices	No		Communications protocols and algorithms	J61.2.0 - Wireless telecommunications activities	2015	None	CTTC
General advancement of knowledge	New advances in device management protocols for low resources devices.	NO		M2M devices	J61.2.0 - Wireless telecommunications activities			SWIR
General advancement of knowledge	LDPC code design for efficient multicast transmission	NO		M2M devices	Wireless Communication; M2M systems	approx. 2020		TUD

Exploitation of R&D results via standards	Promotion of new mechanisms for coverage extension and scalability in LTE-like communications systems for M2M	NO		Performance measures of a LTE-like communication system	Research and experimental development on natural sciences and engineering	Contributions to 3GPP standardisation 2013-2016		Owner: Alcatel-Lucent
Exploitation of R&D Results via standards	Optimised LTE-based radio interface for low data rate M2M services - Industry SIG formed to agree approach for implementation of the above, using EXALTED results as input, where available	YES	juin-14	Network and protocol architectures for efficient carriage of M2M user data and network signalling	Wireless telecommunications activities	First draft specification Jun-2014 (depending on outcome of initial studies and LTE WI progress)	Not yet identified	Vodafone Group: Commercial entities including network operators, infrastructure and device suppliers.
Commercial exploitation of R&D results	Differentiating features in future Alcatel-Lucent base station product releases	YES		LTE-M enabled base station	Manufacture of communication equipment	Release of products 2014-2018		Owner: Alcatel-Lucent

8. Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when Grant Agreement number is entered.*

Grant Agreement Number:

258512

Title of Project:

EXALTED

Name and Title of Coordinator:

Dr. Thierry Lestable

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?

- If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports?

0Yes 0No

Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 'Work Progress and Achievements'

2. Please indicate whether your project involved any of the following issues (tick box) :

NO

RESEARCH ON HUMANS

- Did the project involve children?
- Did the project involve patients?
- Did the project involve persons not able to give consent?
- Did the project involve adult healthy volunteers?
- Did the project involve Human genetic material?
- Did the project involve Human biological samples?
- Did the project involve Human data collection?

RESEARCH ON HUMAN EMBRYO/FOETUS

- Did the project involve Human Embryos?
- Did the project involve Human Foetal Tissue / Cells?
- Did the project involve Human Embryonic Stem Cells (hESCs)?
- Did the project on human Embryonic Stem Cells involve cells in culture?
- Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?

PRIVACY

- Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?
- Did the project involve tracking the location or observation of people?

RESEARCH ON ANIMALS

- Did the project involve research on animals?
- Were those animals transgenic small laboratory animals?
- Were those animals transgenic farm animals?

• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		
Work package leaders		
Experienced researchers (i.e. PhD holders)		
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	
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Of which, indicate the number of men:	
---------------------------------------	--

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project? ☐ Yes
☒ No

6. Which of the following actions did you carry out and how effective were they?

- | | Not at all
effective | Very
effective |
|--|----------------------------------|---|
| ☐ Design and implement an equal opportunity policy | ☒ | ☐ ☐ ☐ ☐ |
| ☐ Set targets to achieve a gender balance in the workforce | ☒ | ☐ ☐ ☐ ☐ |
| ☐ Organise conferences and workshops on gender | ☒ | ☐ ☐ ☐ ☐ |
| ☐ Actions to improve work-life balance | ☒ | ☐ ☐ ☐ ☐ |
| ☐ Other: | | |

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

☐ Yes- please specify

☒ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

☒ Yes- French course at Supélec on M2M

☐ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

☐ Yes- please specify

☒ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

☐ Main discipline²: 1.1

☐ Associated discipline²: 2.2

☐ Associated discipline²:

G Engaging with Civil society and policy makers

- 11a Did your project engage with societal actors beyond the research community? (if 'No', go to Question 14) ☐ Yes
☒ No

- 11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

☒ No

☐ Yes- in determining what research should be performed

☐ Yes - in implementing the research

☐ Yes, in communicating /disseminating / using the results of the project

² Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?		☐ ☒	Yes No
12. Did you engage with government / public bodies or policy makers (including international organisations)			
☒ No ☐ Yes- in framing the research agenda ☐ Yes - in implementing the research agenda ☐ Yes, in communicating /disseminating / using the results of the project			
13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers? ☐ Yes – as a primary objective (please indicate areas below- multiple answers possible) ☐ Yes – as a secondary objective (please indicate areas below - multiple answer possible) ☒ No			
13b If Yes, in which fields?			
Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid	Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport

13c If Yes, at which level? ☐ Local / regional levels ☐ National level ☐ European level ☐ International level										
H Use and dissemination										
14. How many Articles were published/accepted for publication in peer-reviewed journals?	10									
To how many of these is open access³ provided?										
How many of these are published in open access journals?										
How many of these are published in open repositories?										
To how many of these is open access not provided?	10									
Please check all applicable reasons for not providing open access:										
☒ publisher's licensing agreement would not permit publishing in a repository ☐ no suitable repository available ☐ no suitable open access journal available ☐ no funds available to publish in an open access journal ☐ lack of time and resources ☐ lack of information on open access ☐ other ⁴ :										
15. How many new patent applications ('priority filings') have been made? <i>("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).</i>	13									
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark									
	Registered design									
	Other									
17. How many spin-off companies were created / are planned as a direct result of the project?										
<i>Indicate the approximate number of additional jobs in these companies:</i>										
18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project: <table border="0"> <tr> <td>☐ Increase in employment, or</td> <td>☐ In small & medium-sized enterprises</td> </tr> <tr> <td>☐ Safeguard employment, or</td> <td>☐ In large companies</td> </tr> <tr> <td>☐ Decrease in employment,</td> <td>☐ None of the above / not relevant to the project</td> </tr> <tr> <td>☒ Difficult to estimate / not possible to quantify</td> <td></td> </tr> </table>			☐ Increase in employment, or	☐ In small & medium-sized enterprises	☐ Safeguard employment, or	☐ In large companies	☐ Decrease in employment,	☐ None of the above / not relevant to the project	☒ Difficult to estimate / not possible to quantify	
☐ Increase in employment, or	☐ In small & medium-sized enterprises									
☐ Safeguard employment, or	☐ In large companies									
☐ Decrease in employment,	☐ None of the above / not relevant to the project									
☒ Difficult to estimate / not possible to quantify										
19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (FTE = one person working fulltime for a year) jobs:	<i>Indicate figure:</i> 81									

³ Open Access is defined as free of charge access for anyone via Internet.

⁴ For instance: classification for security project.

Difficult to estimate / not possible to quantify	☐												
I Media and Communication to the general public													
20. As part of the project, were any of the beneficiaries professionals in communication or media relations? ☐ Yes ☒ No													
21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public? ☐ Yes ☒ No													
22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project? <table border="1"> <tr> <td>☐ Press Release</td> <td>☐ Coverage in specialist press</td> </tr> <tr> <td>☐ Media briefing</td> <td>☐ Coverage in general (non-specialist) press</td> </tr> <tr> <td>☐ TV coverage / report</td> <td>☐ Coverage in national press</td> </tr> <tr> <td>☐ Radio coverage / report</td> <td>☐ Coverage in international press</td> </tr> <tr> <td>☐ Brochures /posters / flyers</td> <td>☒ Website for the general public / internet</td> </tr> <tr> <td>☐ DVD /Film /Multimedia</td> <td>☐ Event targeting general public (festival, conference, exhibition, science café)</td> </tr> </table>		☐ Press Release	☐ Coverage in specialist press	☐ Media briefing	☐ Coverage in general (non-specialist) press	☐ TV coverage / report	☐ Coverage in national press	☐ Radio coverage / report	☐ Coverage in international press	☐ Brochures /posters / flyers	☒ Website for the general public / internet	☐ DVD /Film /Multimedia	☐ Event targeting general public (festival, conference, exhibition, science café)
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☐ Brochures /posters / flyers	☒ Website for the general public / internet												
☐ DVD /Film /Multimedia	☐ Event targeting general public (festival, conference, exhibition, science café)												
23 In which languages are the information products for the general public produced? <table border="1"> <tr> <td>☐ Language of the coordinator</td> <td>☒ English</td> </tr> <tr> <td>☐ Other language(s)</td> <td></td> </tr> </table>		☐ Language of the coordinator	☒ English	☐ Other language(s)									
☐ Language of the coordinator	☒ English												
☐ Other language(s)													

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

- 1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
- 1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
- 1.3 Chemical sciences (chemistry, other allied subjects)
- 1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
- 1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2. ENGINEERING AND TECHNOLOGY

- 2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
- 2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
- 2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

- 3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
- 3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
- 3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

- 4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
- 4.2 Veterinary medicine

5. SOCIAL SCIENCES

- 5.1 Psychology
- 5.2 Economics
- 5.3 Educational sciences (education and training and other allied subjects)
- 5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary, methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

- 6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
- 6.2 Languages and literature (ancient and modern)
- 6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]