PROJECT FINAL REPORT

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Project coordinators: Prof. Attila Bilgic, Ruhr-Universitaet Bochum, Germany

Dr. Maria Elizabeth Gonzalez, Ruhr-Universitaet Bochum, Germany

Tel: +49-(0)234-32-29141

Fax: +49-(0)234-32-14102

E-mail: attila.bilgic@rub.de, elizabeth.gonzalez@rub.de

Project website address: www.emuco.eu

1. FINAL PUBLISHABLE SUMMARY REPORT

ICT-eMuCo (www.emuco.eu) is a European project with a total budget of 4.6M€ which is supported by the European Union under the Seventh Framework Programme (FP7) for research and technological development with 2.9M€. This project is coordinated by Ruhr-Universität Bochum, which is known as one of the biggest universities in Germany. The strong academic and industrial partners Technische Universität Dresden (Germany), University of York (United Kingdom), "Politehnica" University of Timisoara (Romania), Infineon (Germany), Telelogic (Sweden) and ARM (United Kingdom) are also in the consortium.

The evolution of the radio access technologies has enabled the mobile phones to offer a bigger range of services than voice services oriented mobile phones used to give. As consequence, the mobile phones have evolved to what is known as smartphones, currently popular examples are Blackberry and iPhone, which offer some web amenities and have become the dominant branch in the handheld mobile communication business over the last years and are still rapidly growing in the market. Although at present day smartphones have satisfied a pent-up market demand, it is expected that there will be an exponential growth in the usage of multimedia applications such as video streaming, video conferencing, complex graphics etc., rising the computational performance demand, which can not be pursued further by accelerating the processor clock. At the same time, the coexistence of multiple software environments will be a must in order to offer all demanded services to the user. The contradiction of exponentially increasing computational performance requirements and low power consumption in combination with high flexibility can be solved by a multi-core approach, homogeneous or heterogeneous in combination with virtualization techniques.

ICT-eMuCo engages in the investigation of the fundamental principles of this approach, i.e.

- the suitability of a multi-core architecture for mobile devices including the power saving mechanisms (through e.g. core "hot-plugging")
- a virtualization approach to abstract the application software layers from the specific implementation of the hardware architecture
- the potential hardware support for an efficient implementation of the virtualization in terms of power and clock cycles
- the required programming paradigms and tool support to efficiently use the multi-core architecture

In this sense, the project has generated a series of results which can be seen from three different perspectives: software platform perspective, hardware platform perspective, and application layer perspective (See Figure 1 for reference).

The eMuCo project developed a **software platform** or operating system infrastructure composed by three main layers as can be seen in Figure 1, which offers the co-existence of several protocol stacks into the modem sub-system together with a pluggable Rich-OS based applications sub-system. The microkernel

layer provides a minimal set of kernel functionality and allows building user-level services offering good isolation characteristics as it allows separating sub-systems from each other. Therefore, it is an absolutely necessary basis for secure systems since it allows isolating potentially untrusted components while maintaining security properties for others. The resource layer contains all the software needed to run the applications. It is basically divided in three parts:

- The virtualization and run time environment contains the needed software to manage the physical resources such as low-level drivers, memory allocation, load balancing, etc.
- The load balancer, which is one of the core components in the resource layer to support multi-core, provides the services such as allocation of task/thread on the multiple cores, priority management and thread monitoring.
- The adaptability sub-layer offers services to the applications such as high-level driver services.

The software platform infrastructure developed within the project is a valuable base for subsequent projects in industry and academia as well as it offers interesting perspectives for future research topics in the area of small and trustworthy systems. eMuCo laid the foundation for an operating system that builds upon the state-of-the-art security mechanism in operating system construction and thus leverages the base for future security enhanced systems. The system supports the major platforms in both the embedded and desktop/server areas, supports current multi-core systems for both architectures and is well prepared for future architectural challenges. Additionally, the load balancer concept which has been developed within the eMuCo project has opened new dimensions in performance optimization and power consumption reduction in multi-core embedded systems. While the basic architecture, designed as a user level component facilitates a flexible system configuration, the theoretical and practical work towards service contract based scheduling considers the capability of such devices to operate at higher frequencies than previous solutions and support real time operations in terms of achieving deadlines rather than the previous techniques of resourcing the device so that deadlines are always met through designing to worst-case execution.

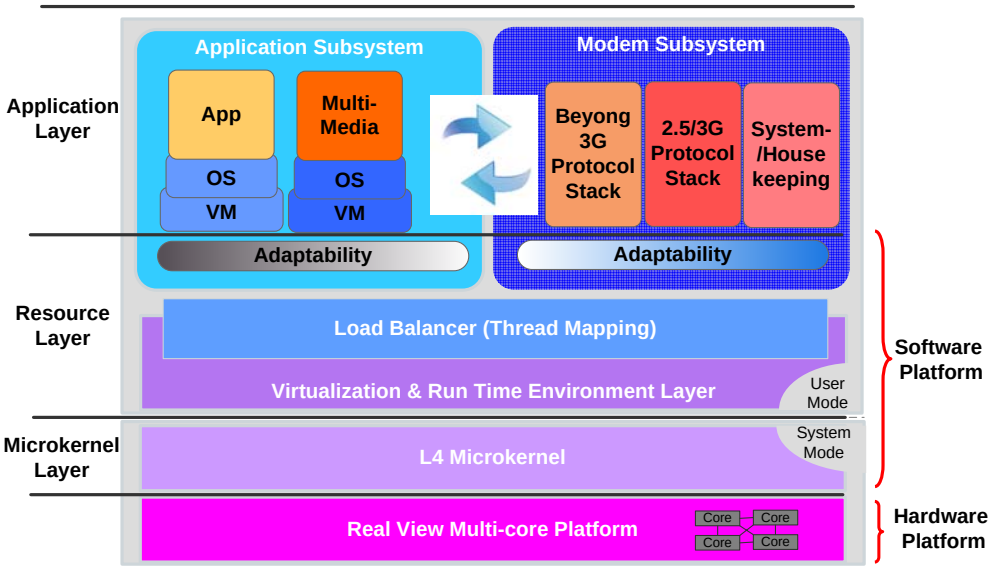

Figure 1: Conceptual Software Layer Architecture

From the **hardware platform** perspective, at the start of the eMuCo project there were no examples of such symmetric multiprocessing (SMP) capable multicore platforms in mobile devices. So two virtual reference platforms were called out as initial project deliverable based on a virtual instantiation of the ARM RealView MultiCore evaluation board on which the subsequent project initiatives could focus: “The ARM System Generator-Model Debugger Virtual platform” and the “Reference Virtual Platform for MultiCore Mobile Devices”. The first permits a common software framework to be developed that includes operating system ports that forms the bases for both the hardware and virtual platform. The second was built with the purpose to evaluate the implemented eMuCo software and in particular the protocol stack of the modem subsystem. Furthermore, to provide a baseline representation and reference solution on a current state of the art mobile communication platform, the base eMuCo software platform was ported on to one single-CPU based Infineon mobile communication platform (Infineon XG618 ES1.1 board). By running the modem subsystem data path component of the LTE protocol stack together with multimedia applications on the same core, it was demonstrated that the eMuCo software platform allows running on the same CPU the modem and application subsystem keeping the security and real time characteristics required for mobile equipments, which is not possible with the current state of the art of the mobile software platforms.

In order to investigate techniques for improved energy efficiency, the Reference Virtual Platform was then utilized to develop on the concepts of “Big/Little” core host architecture and accelerator subsystem which in combination with the suitable host should provide the required processing capacity to the most critical applications. These work outputs a number of findings associated with power analysis of multicore platforms, and the temporal costs associated system migration between cores. The basic idea of the “Big/Little” architecture is to have two fully ISA compatible cores, with a high performance instantiation which is called the big core and a low-power instantiation called the little core. The names stem from the respective chip areas required to design these cores. The “Big-Little” architectures explored in the eMuCo project hold promise for future high-performance mobile devices which consume very less power when intensive computation is not required. The requirement for such devices is obvious as users typically want more computational power in their mobile handsets for doing internet browsing, checking their mail, gaming, video telephony while at the same time expect long battery life. Also with rising leakage currents for lower fabrication geometries it is understandable that a single core processor will not be able to cater to the requirements for both high computational performance and low power operation. Hardware, System architectures and software approaches have been looked into as part of this study. The feasibility of such an approach has been quite well established and may significantly impact the product roadmap of eMuCo partners as e.g: ARM.

General purpose multi-core systems for systems and devices are an emerging technology with limited adoption currently and no clear development methodology. The **application layer perspective** comes then to be an important key to determine the feasibility of bringing multicore architectures to a commercial product since such platforms will only provide its best performance with multithreaded applications. Most of the today’s programmers are not able to think in MultiCore systems, that is to think in parallelism, while keeping the constraints of mobile embedded systems. We are all trained to think in sequential code. So here model-driven development (MDD) can

give a big step forward. It will enable to do an efficient programming on the multi-core architecture. MultiCore development through the use of model driven development (MDD) provides the added benefit of trial-and-error, or trade-off study for the purpose of converging on final system architecture. A proof of concept was provided by developing an evaluation version of the data plan of the LTE protocol stack using the IBM Telelogic SDL Suite tool, allowing for uploading and downloading data from the network. The methodology used in eMuCo represents a series of best-practices for multi-core based next-generation wireless handset systems. A better understanding of both the eMuCo architecture from the architectural perspective, as well as power efficiency aspects from the application point of view, have been experienced by exploring the idea of a software component for application power efficiency assessment. As part of the initial goals of the project, the UML software system modeling environment evolved to consider the execution of the model on a targeted virtual platform. Rhapsody leverages all structural and behavioral model views to produce an executable application on MultiCores. Additionally, the integration on one core competitive Infineon platform (Infineon XG618 ES1.1 board) evolved to integrate the full product 3GPP protocol stack Multi Mode Type II Rel. 6 to explore the commercial implementation feasibility of different software architectures and its compatibility with existing large legacy software. The integration gave positive results in the real time capabilities of the proposed eMuCo software platform and a methodology for porting big legacy software to the eMuCo software platform was developed looking forward to a future commercial implementation.

The eMuCo project set out through research and practical investigation to demonstrate the premise that MultiCore processors in combination with virtualization technology could be used within future generations of mobile communication platforms so that they could harness their speculated performance and power efficiency. To the end of the project, the project completed two series of complementary demonstrators to provide a realization of the concepts and application of the research developed within the project: realization of eMuCo concepts through hardware demonstrators and analysis and investigation through virtual demonstrators. The final outcomes provide the necessary information on the suitability of the MultiCore computing system for future mobile devices which definitely will dominate the markets of consumer electronics and therefore are of fundamental importance for the European industries. Maintaining the leadership in these markets also guarantees technology leadership in many areas as e.g. embedded devices, embedded software, semiconductors and System-on-Chip (SoC) development. The successful developments and technology transfer of the eMuCo project already found its way in todays multicore mobile devices, although predominantly in the high-end segment of smartphones within the computing subsystem for the applications The significant dissemination activities of all the eMuCo partners paved the way of the developed base technology into the commercial platforms and will soon lead to great acceptance in the whole embedded computing system market. The introduction of higher performance and security in mobile computing systems through the implementation of MultiCore and virtualization will bring unthinkable changes in the services the people can get to increase their life standard as e.g. higher integration between families spread over the world. The eMuCo project has thus been successful in its mission in terms of both technological advancement to enable this as well as social impact.

General information about the project and the consortium is publicly available at the project homepage www.emuco.eu. It includes also press releases, newsletters and other publications to be found in Dissemination as well as an internal area with restricted access.

List of beneficiaries

Ruhr-Universität Bochum Institut für integrierte Systeme, IC-FO 03/560 Universitätsstr. 150 D-44780 Bochum Germany	
Prof. Dr.-Ing. Attila Bilgic	attila.bilgic@ruhr-uni-bochum.de
Dr. Maria Elizabeth Gonzalez	elizabeth.gonzalez@ruhr-uni-bochum.de

Infineon Technologies AG Am Campeon 1-12 D-85579 Neubiberg Germany	
Prof. Dr.-Ing. Josef Hausner	josef.hausner@infineon.com

Telelogic North America / IBM Rational 1821 Walden Office Square Schaumburg, IL60173 USA	
Irv Badr	ibadr@us.ibm.com

ARM Ltd. 110 Fulbourn Road Cambridge CB1 9NJ United Kingdom	
John Goodacre	john.goodacre@arm.com

Technische Universität Dresden Georg-Schumann-Str. 11 D-01187 Dresden Germany	
Prof. Dr. Gerhard Fettweis	fettweis@ifn.et.tu-dresden.de
Prof. Dr. Hermann Härtig	haertig@os.inf.tu-dresden.de

The University of York Heslington, York YO10 5DD United Kingdom	
Dr. Neil C. Audsley	neil.audsley@cs.york.ac.uk

"Politehnica" University of Timisoara Piata Victoriei 2 300006 Timisoara Romania	
Dr. Dacian Tudor	dacian@cs.upt.ro

Project website: www.emuco.eu