1. PUBLISHABLE SUMMARY

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), ARM (United Kingdom) and GWT-TUD (Germany) are also in the consortium.

The evolution of the radio access technologies has enabled mobile phones to offer a bigger range of services than voice services oriented mobile phones used to give. As a consequence, the mobile phones have evolved to the called Smartphones, as 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 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 cannot 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 concentrates on 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

The final outcome provides the necessary information on the suitability of the multi-core 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 overall main objective of the first reporting period of ICT-eMuCo, from February 2008 to November 2008, was to create a concept for the HW and SW architectures for a mobile reference platform. As well, the requirements for its implementation were

analized and basic use cases set-up. An LTE protocol stack model was chosen for the requirement analysis and modem software architecture definition in the modem subsystem. The IMS framework and the H264 video codec were chosen as reference multimedia applications in the application subsystem. It resulted in a conceptual software architecture composed by three main layers as 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. Depending on the implementation of the decision making of the load balancer, it could have a static, semi static or dynamic implementation.
- The adaptability sub-layer offers services to the applications such as high-level driver services.

The application layer is the user of the services. In the application sub-system, para-virtualization allows running a broad set of existing applications in new environments by using virtual machines to run whole operating systems along with their applications. In the modem sub-system, the protocol stack does not have virtual cores. It is just a “normal” multi-threaded application, which will be scheduled among cores by the load balancer and on the single cores by the kernel. Additionally the applications, both in the application sub-system and the modem sub-system, should be multi-tasking/multi-threaded to take advantage of the multi-core hardware platform.

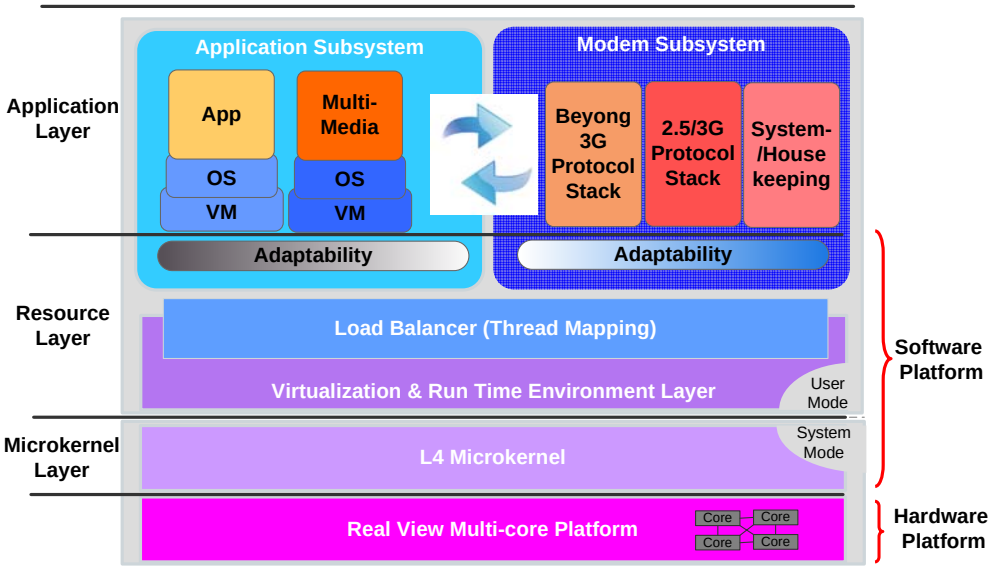

Figure 1: Conceptual Software Layer Architecture

The overall main objective of the second reporting period of ICT-eMuCo, from December 2008 to July 2009, is to develop the main components of the mobile reference platform conceptialized during the first reporting period.

The **application layer** (see Figure 1) is basically divided according the main functionalities of the mobile phones: 1) applications that run at the application subsystem and 2) applications that run at the modem subsystem. The execution support and portability are the most critical aspects at the **application layer** when dealing with software applications for mobile embedded systems. In this sense, the **eMuCo software platform** offers full portability to the user's applications by virtualization techniques and standardized interfaces (e.g. POSIX). Nevertheless, multiple cores will only provide more speed when used with multi-threaded/multi-task software. We have identified that the development process of applications on multicore systems should consider three main aspects which are currently under study: 1) architectural perspective, 2) software engineering and 3) managing dimensioning. The effort of porting legacy applications to the eMuCo platform is being studied by the porting of a full product protocol stack as the Infineon Multi Mode Type II Rel. 6 stack to the eMuCo software platform. At the same time, the portability of the eMuCo software platform itself has been evaluated by porting it to a full-blown mobile phone platform as the Infineon XMM™ 6180 Multimedia Platform Solution, which has given promissing results.

The **resource layer** has been enhanced in order to meet the project's goals. An initial ***load balancer*** skeleton was added to enable the sharing of the multi-core platform between the modem and application subsystem. ***Virtualization*** is supported in different flavours. Para-virtualization, as used on the ARM architecture, is implemented by using the provided kernel and runtime environment functionality and adapting the guest operating system to those interfaces. Full virtualization uses a kernel supplied virtual machine container that allows the virtual machine monitor to drive the guest operating system using hardware features. Both virtualization techniques are subject to the same security policies as the other parts of the system so that guest operating systems with their applications are isolated from each other and from other parts of the system. Furthermore, secure access to I/O resources within the eMuCo environment is enabled by having the ***device drivers as a user-level application*** at the called adaptation sublayer in Figure 1. Also, an efficient shared-memory mechanism was implemented to enable communications between L^4Linux-based applications and L4Re applications running in parallel outside the virtual machine. The **microkernel layer**, which is based on the L4 microkernel, has been enhanced to support load balancing by gathering and retrievel the necessary statistics.

Further investigations have been done in the ***load balancer*** for future enhancements of the **resource layer.** A schedulability analysis based on contract models that assumes a two-level resource contract model is on going. In such a model, a contract describes not only the minimum resource requirements (in the form of minimum CPU time requirement, or *budget*, and maximum *period*) but also the parallelism needed (i.e. the number of cores that will provide the required budget in the given period). An additional grade of complexity as voltage and frequency scaling will be included in the future.

Many investigations are in progress on the **hardware platform**. The exploration of the hardware platform has been divided in three main areas: 1) *exploration of the host* which aims to explore heterogeneous multi-cores with uniform ISA in order to get high-performance when needed and the benefit of low-power operation at other times. 2) *exploration of hardware accelerator subsystem* which in combination with the suitable host should provide the required processing capacity to the most critical applications. 3) exploration of the processor and memory subsystem configuration which aims to do hardware and software co-design at the architecture exploration level and customize the processor and memory subsystem of a selected platform in order to meet the timing requirements of the protocol stack on one hand, and maintain a good balance between area and power overhead on the other hand. These activities started with promising progress and first architectural proposals.

Several principles of the eMuCo mobile platform reference architecture will be shown in three demonstrations, one based on the ***MP virtual prototype***, another based on the ***ARM MP evaluation board*** and one on a competitive ***one core Infineon mobile reference platform***. First concepts and integration plans have been developed and pre-integrations have been done on all three platforms. The one core reference platform actually consist of a highly integrated SoC with seven cores but the computing system running all applications (modem and multimedia) has only one ARM11. Preliminary benchmarkings have been carried out on these three platforms using the eMuCo software platform and different types of stacks implementations and different applications. Basically the protocol stacks used for the benchmarking and demonstration purposes have been: 1) An LTE data plane multithreaded implementation with Telelogic's SDL tools and model driven code generation. 2) A hand coded C implementation of LTE data plane protocol stack and 3) the Infineon Multi Mode Type II Rel. 6 stack, which is a full product protocol stack.

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.

Contact:
Prof. Dr.-Ing. Attila Bilgic
Coordinator

Ruhr-Universität Bochum
Integrierte Systeme
IC-FO 03/560
Universitätsstrasse 150
D - 44780 Bochum
GERMANY

Phone: +49-(0)234-32 - 29141
Fax: +49-(0)234-32 - 14102
E-mail: attila.bilgic@is.ruhr-uni-bochum.de