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TRECOM: Reliable distributed embedded real-time systems based on components TIC2002-04123-C03

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Abstract

The TRECOM project is aimed at developing methods and tools for building distributed, embedded real-time systems with a high level of reliability and quality of service requirements. The approach is based on using software component technologies integrating specification and analysis methods for system properties related to reliability, quality of service, and temporal behaviour.

Three abstraction levels are considered: execution and communication platforms, middleware and component support, and applications. The application fields that will be considered are: multimedia systems, ubiquitous systems, and industrial control systems, as well as other related fields where strict reliability requirements are common (high integrity systems).

The expected results include: real-time kernels with high-integrity and quality-of - service characteristics, communication subsystems and middleware for systems with this kinds of requirements, study reports on system analysis methods and development tools for building distributed real-time systems. The methods and tools that will be developed in the project will be applied in three application domains that will act as demonstrators: multimedia systems, ubiquitous systems, and industrial control systems.

1 Project objectives

The global aim of the project is to develop methods and tools which are appropriate for building embedded, distributed real-time systems with a high level of reliability and quality-of-service (QoS) requirements.

The project is organised around three abstraction levels: platforms, middleware, and applications. Topics to be dealt with at each level include:

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- **Platforms**
  - Real-time kernels and communication protocols for distributed embedded systems.
  - Operating system components for real-time QoS management.
  - Configuration and analysis tools for real-time systems.
  - Response -time analysis techniques for distributed real-time systems.
- **Middleware**
  - Component models and infrastructure for real-time systems with QoS requirements.
  - Architectural models for achieving QoS control in networks and terminal devices.
  - Support components for distributed embedded systems and industrial networks.
  - UML profiles and tools for embedded real-time systems.
- **Applications**
  - Multimedia systems.
  - Ubiquitous systems.
  - Industrial control systems.
  - High integrity systems.

A fourth kind of objectives is related to methods and tools for supporting the above objectives.

2 Level of success

Significant results have already been achieved in most of the above target areas, with no special difficulties in any of them. Some of these areas have benefited from synergy from other concurrent projects. The next paragraphs describe in detail the most important results within each work area.

2.1 Platforms

2.1.1 Real-Time Kernel for Resource Management

Based on previous work on the HOLA-QoS architecture [1, 2], a new version of the HOLA resource management kernel has been developed by the UPM team, with an enhanced design including power management capabilities for embedded systems. This enables enlarging the life of the battery and, in some cases, controlling the temperature of some devices. The power management module includes an API for higher level layers, while keeping the possibility of acting locally on such parameters as CPU clock frequency or network controller operating modes.

2.1.2 Platform for high-integrity distributed systems

The work in this area is based on previous work on the ORK kernel [3, 4, 5]. As a first step, a new version of ORK for PC platforms, based on the most recent GNAT version[1], has been developed by the UPM team. The kernel has been used as a test bench for new real-time features proposed for the forecoming Ada 2005 standard, especially execution-time clocks and timers. The experience gained in such activity has been translated to the real-time Ada community through the participation in the *International Real-Time Ada Workshop (IRTAW)* and the Ada *High-integrity Rapporteur Group (HRG)*.

The use of ORK for distributed systems is currently being investigated. In order to build an appropriate test bench, deterministic network drivers suitable for the RT-EP protocol [6] are being developed. A communications architecture based on ORK and PolyORB [7] is being designed.

2.1.3 RT-Linux platform for embedded systems

The work in this area is aimed at providing a practical basis for using RT-Linux[2] in small embedded systems. It builds up on previous results from the UPV team [8]. Software packages for installing a minimal RT-Linux system [9], and for running a stand-alone RT-Linux platform [10], have been developed. Other results include a dynamic memory manager for RT-Linux, and execution support packages for Ada 95 [11].

2.1.4 POSIX packages for RT-Linux and MaRTE OS

The work that has been carried out in this area is aimed at providing a minimal POSIX API for RT-Linux, as well as implementing the POSIX traces functionality [12] on RT-Linux and MaRTE OS , a minimal POSIX real-time kernel developed by the UC team [13].

2.1.5 Scheduling extensions for QoS in RT-Linux

An application-defined scheduler for RT-Linux and MaRT OS has been developed [14], that can be used to provide QoS control in Rt-Linux systems.

2.1.6 Distributed real-time platform for minimal systems

The work in this area adds up on previous developments on MaRTE OS, a minimal POSIX real-time kernel developed by the UC team [13]. Communication drivers for CANbus and Ethernet (RT-EP) [6] have been added to MaRTE OS, and a new transport layer has been developed [15].

An implementation of the distributed annex of Ada 95 has been developed, running on the RT-EP and CAN protocols and the MaRTE OS kernel [16]. A thorough assessment of the annex has lead to a a proposal for real-time extensions which can be implemented in the framework of the current standard [17].

All the protocols and mechanisms developed in this area have been modelled and included in the MAST tool [18].

[1] http://www.act-europe.fr/

[2] http://bernia.disca.upv.es/rtportal/

2.2 Middleware

The aim of this package is to develop new technologies in middleware and software components for real-time systems with QoS requirements. Significant results have been obtained in the following areas:

2.2.1 Component infrastructure for QoS

The activity in this area has been directed to the integration of the specification methods described in section 2.3.3 in a component-based architecture based on containers. In this way specifications are accessible to implementations, and can be used for negotiating or monitoring QoS levels [19, 20, 21].

2.2.2 Middleware with QoS control

The initial objectives of this task were based on the CORBA 3 standard, which has had a comparatively low industrial acceptance. The activity has been redirected to web services used as a weakly coupled middleware. Work has been done on defining QoS parameters for service-level QoS, based on SOAP and HTTP, and measuring and monitoring them. A set of prototypes has been developed using modelling and code generation tools such as Objecteering, EMF/Eclipse, JoNAS, and JDK 1.3 [22, 23].

2.2.3 Reference architecture for QoS in terminal devices

The work in this area has been based on the HOLA-QoS architecture, developed by the UPM team in a previous project [1]. The architecture has been enhanced with power consumption control capabilities, which is a fundamental issue in mobile devices. A global management approach has been used, taking into account parameters from different devices [24]. A pilot implementation is currently being developed, instantiated on an IPAQ 5500 PAD running Linux.

2.2.4 Component-based reference architecture for QoS in routers

A layered architecture is being developed which is intended to support three different kinds of traffic on a single Ethernet network: conventional TCP/IP traffic, hard real-time traffic, and traffic with QoS requirements [25, 26].

2.2.5 Support for distributed objects in industrial networks

A set of software packages have been developed in order to provide support for distributed objects under RT-Linux. Among them are network drivers, a TCP/IP stack, a TDMA-based protocol for deterministic Ethernet access, a QoS layer, and a minimal CORBA protocol based on ORBit2 [27, 28].

2.2.6 Component technology for embedded real-time applications

As a first step in this activity area, existing component technologies have been assessed with respect to real-time systems requirements. The conclusion is that current technologies such as

CCM, DCOM, or EJB, are not appropriate for hard real-time systems. Consequently, a new methodology called ACA (Ada Component Architecture), in which a component is defined as an Ada module with a detailed specification of the usage contract, the instantiation contract, and the real-time model, has been developed [29]. The ACA methodology has been tested on two kinds of real-time components that have developed and implemented on top of MaRTE OS.

The methodology is supported by a software development environment called CBADE (Component-Based Application Development) [30], which has been implemented using XML technology in order to make it easier to integrate with standard CASE tools.

2.3 Methods and tools

2.3.1 Tools for high-integrity systems analysis

This activity is oriented towards developing static and dynamic analysis tools for Ada high-integrity applications. A test harness and a collection of tests for this kind of systems has been developed [31], using open source technologies.

A characterization of the timing properties of the ORK kernel has been performed, which enables detailed response time analysis of Ravenscar Ada applications built on top of this kernel [32].

2.3.2 Tools for developing components with QoS control

The work in this area has been aimed at integrating CPU reservation mechanisms and risk mitigation mechanisms in QoS-aware components [19, 22]. The last topic has given raise to a collaboration with Thales in the area of component-based architectures for traffic control systems, and will be continued in the IST project *Modelware*.

2.3.3 UML profile for QoS requirements specification

This profile defines UML extensions for the description of extra-functional properties in UML models [33][34]. The extensions have been used in some industrial projects, and some prototype tools have been developed in the project.

The UPM team has participated in the OMG Architecture Board, from which a proposal for an *UML Profile for Modelling Quality of Service and Fault Tolerance Characteristics and Mechanisms* has been issued. The UPM representative is responsible for the final writing of the document, which has been recently approved [35].

2.3.4 UML profile for ubiquitous systems

This activity has been focused on ubiquitous systems supporting localization, identification and positioning with RFIDS *(smart tags)*. Service-oriented systems (based on the Open Services Gateway initiative -OSGi- standard) have been explored as a possible implementation approach, and architectonic principles for this kind of systems have been investigated. Methods for requirements specification *(Enager tool and method)* [36, 37, 38]), deployment *(JBones* [39]), configuration, testing [40], and process management(based on JMX) for this kind of systems have been developed by the UPM team [22].

2.3.5 Configuration and generation tools for RT-Linux-based embedded systems

A tool supporting configuration and generation of embedded systems using RT-Linux has been developed by the UPV team[3] [10].

2.3.6 Tool for timing analysis of traces

The POSIX tracing mechanism has been adapted to a minimal real-time kernel and implemented in MaRTE OS. Based on this work, a tool for helping designers to extract timing information from traces has been developed by the UPV team [12].

2.3.7 CASE environment for component-based real-time applications

The aim of this task, which has recently started, is the implementation of the CBADE environment (see 2.2.6). This task is carried out by the UC team.

2.3.8 Schedulability analysis techniques

The UC team has worked in extending schedulability analysis methods to distributed systems with dynamic priorities, for which new algorithms have been developed [41, 42].

Other topics in which the UC team is working include distributed systems with multiple driving events and blocking times computation for global resources.

2.3.9 Schedulability analysis tools

New models and algorithms have been added to the MAST tool by the UC team, including dynamic priorities and communication drivers developed in other tasks (see 2.1.6 and 2.3.8). An XML-based description is used for information exchange within the tool, and tools for converting this representation to the original MAST representation and vice-versa have been developed. A graphic user interface, currently being finished, completes the set of tools available under MAST[4].

2.4 Applications

Most of the work in this area will be carried out in the third year of the project, but some results are already available.

2.4.1 Ubiquitous systems characterization

An adaptable requirements model and a reference framework for service-oriented architectures have been defined.

2.4.2 Technology map for ubiquitous systems

Work on this subject will be carried out during the third year of the project.

[3] Available at http://www.ocera.org/ vesteve/config.html.

[4] The MAST tools is available at http://mast.unican.es.

2.4.3 Brokering service for multimedia services with QoS negotiation

A prototype of a QoS monitor has been implemented on top of *web services*. The development is based on the QoS API of OSS/J. The prototype has been validated with a couple of service prototypes (traffic alert management based on localisation, and family location service for handicapped persons) developed at UPM.

2.4.4 Embedded system for image acquisition and transmission

This task will be carried out by the UPV and UPM teams during the third year of the project.

2.4.5 Automated packing line

This is a demonstrator of the real-time components technology, to be developed by the UC team during the third year of the project. The original application will be replaced by a similar system, a tile inspection line, for availability reasons.

3 Result indicators

The results which have been obtained up to now are complete and consistent. Platforms, methods, and tools have been developed for a wide variety of real-time systems:

- High-integrity real-time systems: ORK based platform and analysis tools.
- Minimal hard real-time systems: MaRTE-OS platform.
- Temporal analysis: MAST analysis suite and related tools and methods.
- Open real-time systems: RT-Linux platforms, tools, and POSIX compatibility tools.
- QoS-aware real-time systems: HOLA-QoS architecture and tools, UML profiles, power consumption management, and service-based architectures.

Multi-platform result include UML profiles, component technologies, and analysis methods.

A large number of publications (see bibliography, starting at year 2003) have already been generated.

The TRECOM partners participate in the following European projects:

- UPM
  - ARTIST (Advanced Real-Time Systems and Information Society Technologies). IST2001-34820.
  - EFTCoR (Environmental Friendly and cost-effective Technology for Coating Removal). G3RD-CT-2002-00794.
  - HIJA (High-Integrity Java Applications). STREP IST-511718.
  - Modelware (Modelling Solution for Software Systems). IP IST 511731.
  - ASSERT (Automated proof based System and Software Engineering for Real-Time Applications). IP IST 004033.

- UPV
  - OCERA: Open Components for Embedded Real-Time Applications OCERA-IST-35102.
- UC
  - FIRST. Flexible Integrated Real-Time Systems Technology. IST-2001-34140.
  - ARTIST (Advanced Real-Time Systems and Information Society Technologies). IST2001-34820.

All the partners also are in the following Network of Excellence:

- ARTIST2 — Embedded Systems Design (NoE) IST-004527.

The TRECOM partners are collaborating with a number of industrial companies in technology transfer projects, and with the most important research groups in real-time systems, both in Spain and other countries. The three partners were the founders of the annual "Jornadas de Sistemas de Tiempo Real", a meeting of the Spanish real-time research groups that was attended by more than 50 persons on its last edition. All of this makes the TRECOM project ans its partners a key reference point for research in real-time systems in Europe.

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