Research Group Overview: CERES – Centre for Research on Embedded Systems

The Next Challenge for the Communication Society: Co-operating Embedded Systems

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Introduction

In the major reorganisation that took place at Halmstad University during 1999-2000, the new *School of Information Science, Computer and Electrical Engineering* (IDE) was formed. The School of IDE is divided into five laboratories; *Computing and Communication* (CC), Electronics and Physics (EF), Intelligent Systems (IS), Mathematics (MA), and Man and Information technology (MI). The division into laboratories was made in order to focus the research and education into the main areas that are represented at the School of IDE. In this paper we only consider the research directions of CC-lab, which is the laboratory where people with research interests in computer engineering, computer science, telecommunication and data communication and digital hardware design are gathered. After the (as always) turbulent period of re-organisation, a new mission and theme to gather around, was searched for by the newly formed group of researchers and teachers. The result was the formation of the *Centre for Research on Embedded Systems* (CERES) [1]. CERES has its core of researchers at CC-lab but is also open to co-operation with other parts of the school and the University. "*The focus*" of CERES *"is on enabling technologies for co-operating embedded systems and high performance applications*" [1]. The people[1] involved in CERES have a rather broad background spanning complex computer architecture, computer science, data communication, telecommunication, mechatronics, signal processing, and digital hardware design. If a closer look is taken on what the theme "*co-operating embedded systems"* means, it becomes obvious that this broad competence spectrum is a good match to the kind of competence that is needed for successfully dealing with research in the area of co-operating embedded systems.

[1] The CERES core research team today consists of three professors, two adjunct professors, two associate professors, six lecturers, ten Ph.D students and two research engineers.

Motivation

Swedish industry has an internationally leading position in the development of advanced products with embedded computers and communication equipment. As technology progresses in this field, the need for new competence rapidly increases, especially with respect to techniques for integration of intelligent behaviour in smaller, cheaper, and/or increasingly complex products in a way that emphasises security, safety, correctness, usability and predictable performance.

This need is amplified even further due to the expected development of large networks of interacting computers, all embedded in products. Such networked systems of embedded computers [5] will allow information to be collected, shared, and processed in unprecedented ways and make possible fundamental changes in the ways people interact with their environment.

One motivation for this prediction is found when looking back in the mirror of computer history, where the historical development in computer systems strongly indicates that the interconnection of embedded systems is the next natural technological evolution. During the last fifty years the mainframe computer has evolved from a stand alone batch machine, fed with punch cards, into large interconnected server farms, accessed over Internet. The personal computer's interconnection evolution has followed the same pattern, from a limited stand alone device into a globally interconnected advanced multimedia machine. The evolution trend for computers in general seems to follow the statement "the network is the computer" [3]. A qualified guess is that embedded computers will follow the same evolution path, and it has already taken place in limited application areas of embedded systems. An example of such an application area is distributed computer systems in cars, aircrafts and manufacturing industry, in which microprocessors are interconnected by field buses. The interconnection is often limited to a local network and seldom provides any external and global interconnectivity. These interconnected embedded systems often perform different kinds of strict control or/and surveillance tasks, and often have a tight interaction with the physical world. This tight interaction with the physical world is one of the things that distinguishes embedded computers from traditional personal computers and mainframe computers (including networked ones), which mostly handle information processing, displaying and storing.

Another technology area where the evolution towards *high end* networked embedded systems has taken place, is in the cellular telephone system. Here we have seen an evolution from analogue radio telephones, restricted to voice communication, into digital wireless networks where the mobile phone is merged with the PDA into a mobile multimedia terminal. It would be incorrect to say that these systems are strict embedded systems, even if they often are referred to as such. It is probably more correct to say that the digital wireless networks, 3G, and multimedia terminals are a result of the merging of cellular systems and Internet connected personal computers. This development is, however, important for the development of interconnected embedded systems, since at least some embedded computer systems are mobile – a fact that makes the use of wire-lines rather impractical. Even, the use of a dedicated wired network for interconnecting non-mobile embedded computers is probably an unrealistic solution. The problem with wired interconnection becomes obvious if one considers interconnected embedded systems that are "small as dust" [4] – our environment would become a web of wire-lines. Another important technology evolution step is the long-time predicted merge of telecommunication, data communication and entertainment, which takes place in the 3G system. In the wake of this mobile development we see technologies such as Bluetooth, wireless LAN and other wireless short range communication standards evolving. These can perhaps provide the technology fundament for the last 10 centimetres up to 100 meters connectivity necessary for interconnecting embedded systems.

The Challenge

The last decade has shown a tremendous increase in the number of embedded computers that we are surrounded by in our daily life. Embedded computer systems are present almost everywhere; we carry them with us, they are present in our home, in the office, in the car and at the manufacturing plant. This increase in the number of embedded computer systems is sometimes experienced as a complication of our daily life rather than a technology evolution that supports us and eases our burdens in the modern information society. It has, for us as humans, become necessary to interact with a large amount of complex embedded computers. Sometimes a considerable effort is necessary to configure and administrate these embedded systems, often only to get them to provide the correct functionality. In that sense, the largest drawback with embedded systems today is that they tend to have very complex and/or limited graphical user interfaces, which makes them difficult to understand and maintain. As the number of embedded systems increases, we, as users, face the risk of "collapsing under the burden" of fielding and maintaining all of these devices. Potentially, a lot of these devices will not be managed and, as a consequence, these systems will fail to provide the correct functionality. The predicted vision of an "intelligent environment" [2], where embedded devices support and interact with us in a seamless way, seems to have failed.

The major reason for the current failure is that most embedded devices are not interconnected, and thus not able to exchange information. Information exchange, i.e., communication, in a complex system is necessary in order for such a system to create a unified strategy, to form a common rule base for user interaction, and to provide seamless services. One could compare distributed embedded systems to a society: When the society reaches a certain level of complexity, information exchange is necessary for the atomic society member in order to function as a part of a collaborative collective.

The interconnection of embedded systems can, at a first look, seem to be an easy task: Simply equip a micro-processor with a communication interface, and there we have the interconnected embedded system. This is, of course, not true – for a number of reasons: The first reason is the large span of different special purpose processors used, i.e., there are no standardised interfaces and architecture as in personal computers. Furthermore, even if the processor core is the same in two embedded systems, the configuration of I/O and memory mapping differs from design to design. Often, only the processor core is the same, the rest of the hardware design is specially made for a certain application. Embedded systems are special purpose computers, in contrast to personal computers, which are general-purpose computers. Specific added hardware for different interfaces and hardware accelerators for speeding up certain computation tasks are very common. This is a result of that most embedded system are designed for a specific purpose, i.e., a very tight hardware/software co-design process is used during the design phase of an embedded system. This makes it hard to standardise operating systems and to give a general definition of what kind of services that a specific embedded system provides. Even worse, many embedded systems do not have any operating system at all, a fact which severely complicates the execution model of an advanced communication protocol stack. Finally, the greatest challenge of all for interconnecting embedded systems, is to provide compatibility between different devices, provide homogenous communication channels for information exchange and provide mechanisms for service discovery/registry, accessible for the broad plethora of embedded systems.

As said before, embedded systems often have a very tight connection to the physical environment, i.e., they control physical processes and interact with the physical world in a more profound way than personal computers do. This interaction often enforces stringent time constraints on the system, i.e., it is a real time system – often a safety critical one. These time constraints can be disturbed if some non-predictable device suddenly starts to interact with the time-constrained system. In the worst case, such interaction can cause dangerous situations or accidents. Furthermore, the distributed embedded systems that we see today, are often proprietary solutions, into which the manufacturer or service provider not want other than themselves to get direct access. Examples can be found in the car industry, which, during recent years, has evolved from being a strict manufacturer of mechanical systems into a manufacturer of complex mechatronic systems, containing complex distributed computer system with tens of interconnected microprocessors (in some cases hundreds). This development has required a tremendous effort from the car industry, only to see that now they are facing the next evolutionary step – probably an even greater challenge – where the car is becoming externally interconnected, as an actor in telematic and infotainment systems.

Enabling smooth and manageable interconnection of embedded systems is the next big challenge in the development of computer and communication technology [5]. It requires concerted research and engineering efforts within the areas of communication engineering, computer engineering and computer science. CERES has, as a research centre joining these three areas and working in close co-operation with industry, decided to take on this technological challenge, since we believe that the development is of great importance for Swedish industry and the modern society in general.

Present status

As mentioned, the focus of CERES is on *enabling technologies for co-operating embedded systems and high performance applications*. This is reflected in the ongoing research projects, most of which are listed below. Some projects (such as HiSPOT and RSA) have an orientation towards high-performance parallel systems and applications. Some (such as RT-SWITCH, RT-SAN and M-NET) address real-time issues of communication and networking, and a growing number of projects (such as REMOTE and IIEUC) address the problem area of co-operating embedded systems, described above, more directly.

High Speed Optoelectronics for Optical Interconnect (HiSPOT) - Systems and architecture studies for the optical interconnect networks of very high speed (Terabit/s) systems for future telecom and data communication systems, as well as next generation radar systems. Contact: Magnus Jonsson, Bertil Svensson.

Reconfigurable System Architectures (RSA) - The project identifies and evaluates the various ways of utilising reconfigurability and a modular approach in the design of embedded computer and communication systems. It evaluates the efficiency of some emerging, reconfigurable, parallel processing paradigms in selected embedded applications. It identifies the potential advantages of optics as a means of achieving a modular and reconfigurable interconnection structure at the system level and studies different implementation technologies. Solutions are sought that have the flexibility and cost efficiency required in future industrial applications. Contact: Bertil Svensson, Magnus Jonsson.

Budget-Based Design of Embedded Real-Time Systems (BERT) - The project develops an approach for dimensioning of complex real-time systems in early design stages, thus aiming at maximising the implementation success and avoiding costly iterations in the design flow. Contact: Jonas Vasell

Real-time Mobile Telecommunication (REMOTE) - The project develops new coding and decoding techniques (deadline dependent coding) making wireless communication available for time and safety critical applications. It further studies wireless ad hoc networks and their possible use for interconnecting embedded systems and their possible use as communication/network infrastructure in real-time applications. Contact: Urban Bilstrup, Per-Arne Wiberg.

Switched Real-Time Communication for Industrial Applications (RT-SWITCH) - The project studies methods to support traffic with industrial real-time demands over non-real-time LAN-technology, primarily over switched Ethernet. Contact: Magnus Jonsson.

Real-Time System Area Networks (RT-SAN) - The goal of the project is to find communication solutions that meet the increasing demands in embedded systems for performance, service heterogeneity and service levels at the same time as cost-effectiveness is addressed. The approach is to develop methods, protocols, and network architectures that can be used in existing and emerging SAN (System Area Network) standards. Contact: Magnus Jonsson.

Methods for Integration of Heterogeneous Real-Time Services into High-Performance Networks (M-NET) - New high-performance networks with support for the often heterogeneous real-time requirements in emerging (often embedded) applications, such as multimedia, radar signal processing, and telecommunication, are addressed. Contact: Magnus Jonsson.

Infrastructure for Interoperability in Embedded Ubiquitous Computing (IIEUC) - While ubiquitous computing certainly offers completely new opportunities for user applications, there are many technical barriers to overcome, such as interoperability between devices, security, privacy and maintainability of applications. We intend to conduct theoretical and experimental work to investigate the use of tuple space middleware for embedded ubiquitous computing, and to contrast it with other emerging approaches, such as event-based middleware. Contact: Verónica Gaspes, Bertil Svensson.

The intention is to further expand the number of research projects in the area of co-operating embedded systems with the focus on communication. At the moment we are using master thesis works to survey, make pre-studies, etc., in the area of co-operating embedded systems in a broad perspective. Examples of such master thesis works are: *Co-operating robots*, *Embedded WLAN*, *Telematics – Evaluating the Promises of OSGi*, *Bluetooth – MOST gateway*, *Voice Hot-Spot*, *Gossip Network, and Development of Wireless Communication Protocol*.

Collaboration with industry. The development of CERES is supported by a group of companies, and several of the projects are conducted in co-operation with industry. Currently, the following companies are involved in this way: ACREO AB, AXIS Communication AB, Combitech Systems AB, Ericsson AB, Ericsson Microwave Systems AB, Free2move AB, HMS Industrial Networks AB, Innovation Team AB, Volvo Technology Corporation AB, XCube Communication AB. The formation of CERES as an internationally strong research centre is financially supported by the Knowledge Foundation.

Conclusion

In CERES we foresee that the ability of an embedded system to communicate with other systems (or within a distributed, embedded system) is an important part of the system's function. For embedded systems of the future, such demands will be the rule rather than the exception. There is a multitude of important issues to be studied in research, including "Quality-of-Service"-communication over wireless networks or switched networks, short-range and low-power wireless technologies, wireless networking, interoperability, scalability, adaptation to situations, and protection against unauthorised use. Some of these issues demand a multidisciplinary approach, and CERES is built up to be able to cope with them efficiently.

References

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