1 Proposers

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2 Project duration

The project duration is four years.

3 Summary

This proposal addresses fundamental issues in the architecture and design of low-power hand-held multimedia systems, with particular emphasis on energy conservation. The combination of Personal Digital Assistant (PDA) technology, wireless networking and smartcard, when combined and integrated
well, have the potential of replacing all of the things people have to carry around by one small device. The employment of such a device has several challenging implications: it must provide \textit{multimedia functionality}, operate in a very dynamic wireless environment, and be \textit{secure} because it contains personal information and interacts with the - possibly hostile - environment. All these capabilities have to be integrated in one \textit{small} and \textit{light} battery-operated device, implying \textit{ultra-low energy consumption} and \textit{high performance}. Recent research shows that a radical new approach has to be taken in order to fulfil the requirements - in terms of processing power and energy consumption - of future mobile applications. A primary goal of this project is to prove that a \textit{reconfigurable systems architecture} in combination with a QoS driven operating system that can deal with the inherent dynamics of a mobile system, is of fundamental importance to the success of flexible low-power handheld systems. A novel aspect in this concept is that application-specific chip-design is replaced by dynamic reconfiguration and reprogramming. In our opinion, this sheds a new light on the fundamental issues of low-power embedded systems.

4 Project description

4.1 Motivation

In the next decade two trends will definitively play a significant role in driving technology: the development and deployment of personal mobile computing devices and the continuing advances in integrated circuit technology. The semiconductor technology will soon allow the integration of one billion transistors on a single chip [5]. This is an exciting opportunity for computer architects and designers; their challenge is to come up with system designs that use the huge transistor budget efficiently and meet the requirements of future applications. The development of personal mobile devices will give an extra dimension, because these devices have a very small energy budget, are small in size but require a performance which exceeds the levels of current desktop computers. We claim that state-of-the-art system-architectures cannot provide the wealth of services required by a fully operational mobile computer given the increasing levels of energy consumption. Without significant energy reduction techniques and energy saving architectures, battery-life constraints will limit the capabilities of these devices.

4.1.1 Personal mobile devices

The technologies of PDA, wireless networking and smartcard, when combined and integrated well, have the potential of replacing all of the things people have to carry around by one small device. This device that we will call a \textit{Mobile Digital Companion} (MDC), is a small portable computer with a smart card and communications device that can replace cash, cheque book, passport, keys, diary, phone/pager, walkman, radio, maps, etc. The employment of the envisioned Mobile Digital Companion has several challenging implications:

- It must provide \textit{multimedia functionality}
  
  It has been predicted that beyond the year 2000, 90 percent of the computer cycles will be spent on multimedia applications [6]. The MDC is an end-user terminal so image processing, handwriting and speech recognition will be important and real-time properties will be evident as well. The use of real-time multimedia data types like video, speech, animation and music greatly improve the usability, quality, productivity, and enjoyment of these systems. Multimedia applications are characterised by multiple synchronised media streams. Some of these streams (typically video streams) have high bandwidth and stringent real-time requirements, as well as a significant amount of user interaction. Most of the applications we consider require not only a certain Quality of Service for the communication (like high bandwidth and low latency), but also a significant amount of computing power. The compute requirements stem from operations such as compression/decompression, data encryption, image and speech processing, and computer graphics. The most important factors, which will determine the success of the \textit{Mobile Digital Companion}, are the effectiveness and convenience of the system. Therefore the Companion has to have a high
throughput and real-time properties. An extra challenge is that the system has to deal with limited resources (energy, communication bandwidth, processing power, memory, etc.).

- **MDCs work in a very dynamic environment.**
  The MDC should support wireless multimedia communication in a dynamically changing environment. For example, it will have to deal with unpredicted network outage or should be able to change to a different network, without changing the application. It should have the flexibility to handle a variety of multimedia services and standards (like different video decompression schemes and security mechanisms) and the adaptability to accommodate to the nomadic environment, required level of security, and available resources. Eventually even the user might notice these dynamics: for instance he will have to live with Quality of Service changes: a lower audio quality or a change from full colour to black/white picture quality.

- **MDCs are personal devices**
  The MDC contains valuable private information such as electronic money, contracts, cryptographic keys, private addresses etc. Furthermore, because MDCs are used in an open and nomadic setting, the MDC communicates with potential hostile and untrusted service providers. For instance, when the user downloads software from an unknown service provider he may be prone to many forms of attack (viruses, Trojan horses).

- **MDCs must be small and light.**
  The weight and size should be adequate for its purpose: e.g. a hand-held device should fit into your shirt pocket. This implies that it should have an ultra low energy consumption, because only small batteries can be used. As current battery research does not predict a substantial change in the available energy in a battery, energy efficiency plays a crucial role in the architecture of the Mobile Digital Companion.

### 4.1.2 Semiconductor technology

The semiconductor technology is realising chips with substantially smaller features each year. This leads to a magnitude shrink (1/10) of all mask-features in ten years. The industry decreased the energy consumption per operation with a factor of 1/1000 in the past decade. Greatly enhanced performance levels has been achieved e.g. due to a 100-fold increase in the clock speed. Functionality has moved from 16-bit integer arithmetic to 64 bit floating point arithmetic. A 100-fold increase in performance can be expected for the decade ahead. Computer architects are already discussing the architecture of future one billion transistor processor designs. In our view, personal mobile computing will play a significant role as a driving technology in processor design. Other researchers [8] share this view. The two main reasons are the above-mentioned increasing use of multimedia applications and the growing popularity of portable devices. One major obstacle to designing one billion transistor systems is the physical design complexity, which includes the effort devoted to the design, verification and testing of an integrated circuit. A possible solution is to work with a highly regular structure such as the FPFA (Field Programmable Function Array) structure described below. These structures only require the design and replication of a single processor tile and an interconnection structure. Design and verification of a regular structure is much easier. Although the precise formulation of such architectures is complex, as the architecture should be optimal for many applications; the great reward is that the verification of its physical design is much more straightforward, due to the restricted use of automatic routing tools. Furthermore, production level testing is less complicated too due to the repetition of well-defined structures.

In the area of mobile computing it will be an enormous challenge to work with a power budget of less than one Watt. Yet, the architecture must provide the performance for functions like speech recognition, audio/video compression/decompression and data encryption. Power budgets close to current high-performance microprocessors, are unacceptable for portable, battery operated devices. MDCs should be able to execute functions at the minimum possible energy cost. On the other hand they must be flexible and adaptable to environment changes.
Today, a lot of research is mainly focused on performance and (low power) circuit design of individual components. We believe it is more effective to save energy by a carefully designed hardware- and software architecture of the mobile. There is a vital relationship between hardware architecture, operating-system architecture, applications’ architecture and human-interface architecture. For example: the applications can adapt to the power situation if they have an appropriate operating-system API for doing so; the operating system can optimise the battery consumption by adapting reconfigurable components to the required Quality of Service; the hardware architecture can handle the data in such a way that, for critical functions, only a minimum number of components need to be active.

4.2 Objectives
The overall goal of this project is to provide support for high-quality design of mobile computing applications and systems by providing adequate architectural concepts, models and methods. Our primary target is the design of mobile low-power multimedia computers that use reconfigurable architectures for achieving efficiency and performance. This requires vision into trends in mobile systems, applications and technology.

This objective can be subdivided into the following sub-targets, which is also reflected in the AIO proposals:

1. To develop reconfigurable system architectures and devices, which use the chip area effectively, are relatively easy to design and are flexible and adaptive to handle the dynamics of the mobile environment.
2. To develop a QoS based model for reconfigurable mobile computing systems that can be used for modelling and analysing existing as well as future mobile systems, such that their effectiveness and efficiency is improved.
3. To develop efficient operating system functions for reconfigurable systems. The operating system should be flexible and adaptive to the inherent unpredictability of the mobile environment and should be able to control the multimedia streams through the reconfigurable architecture.
4. To guarantee a fast dissemination of state-of-the-art knowledge between academia and industry. This will made concrete through workshops and seminars. In this project we will stimulate, co-ordinate and promote the research on low-power systems and we will serve as a national platform for knowledge exchange on low-power mobile embedded systems. Furthermore, we will use a derived form of knowledge transfer by defining student projects, which will strengthen the collaboration between industry, universities and knowledge institutes.

4.3 Reconfigurable systems architecture
We believe reconfiguration is of fundamental importance to the success of flexible low-power handheld systems. The previous section gives more than enough evidence for the thesis that a radical new approach in the systems architecture has to be taken in order to fulfil the requirements of the MDC, in terms of processing power and energy consumption. We propose a reconfigurable systems-architecture that in combination with a QoS driven operating system can cope with the inherent dynamics of a mobile environment. The system architecture should be flexible and/or reconfigurable in many ways. The main research question is how this reconfiguration can be structured. It is part of this research to find and evaluate new forms of reconfiguration. This is a new research field and to give an impression what kind of reconfigurability we are considering we describe three ways how we think reconfiguration could be done:

- Reconfigurable media streams,
- Reconfigurable processing modules,
- System decomposition.

4.3.1 Reconfigurable media streams
In an earlier project called Moby Dick [33] we found that in low-power systems much energy profit can be gained by improving the component interaction. We experimented with a systems-architecture that accommodated the required functionality, within the energy limitation constrains of a small battery-powered device. This systems-architecture has some similarities with the Desk Area Network in Cambridge [7] and the Pleiades project in Berkeley [2] [4].

In the architecture, we have an organisation of a programmable communication switch surrounded by several autonomous modules. Figure 1 gives a schematic overview of the MDC’s architecture. The functional tasks are allocated to dedicated (reconfigurable) modules (e.g. display, audio, network interface, security, etc.). The switch activates only those data paths actually carrying data.

In our architecture modules are autonomous and can communicate without involvement of the main processor. For example, if a video/audio stream enters the terminal via the network interface, this data is sent directly to the video/audio module, without main processor intervention. The main processor is used only initially to setup the connection. The architecture has a number of premises:

- An energy-efficient communication mechanism for multimedia tasks as well as non-media tasks is provided by a structure of a general-purpose processor accompanied by a set of heterogeneous reconfigurable modules. The modules are capable of performing device or application specific tasks efficiently. For example the display module can decompress a video stream, just before it is displayed on the screen. Dedicated modules can be optimised to execute specific tasks, with minimal energy overhead. Instead of executing all computations in a general-purpose processor, as is commonly done in conventional PDA architectures, the energy- and computation-intensive tasks are executed in optimised reconfigurable modules.

- A reconfigurable internal communication network exploits locality of reference and eliminates wasteful data copies. Memory accesses consume quite a bit of energy and this energy is wasted if the data only occupies memory in transit between two devices (e.g., network and screen or network and audio). As in switching networks, the use of a multi-path topology will enable parallel data flows between different pairs of modules and thus will increase the performance.

- The main CPU is relieved of having to service device interrupts and to perform context switches, or to copy buffers to or from a device every time new data arrives.

- The system avoids wasteful activity: e.g. by using autonomous modules that can be powered down individually and are data driven. The modules can easily adapt their behaviour to changes in the environment, either imposed by the user (when he starts a new or different application) or by resource changes (for example when the network module notices a change in the wireless channel conditions).
• The modules are autonomous. For instance: the wireless communication is designed for low energy consumption by using intelligent network interfaces that deal efficiently with a mobile environment, by using a power-aware network protocol stack, and in particular by using an energy-efficient MAC protocol. The network protocol stack can be handled by the network interface such that the CPU can be turned off for frequent media streams.

4.3.2 Reconfigurable processing modules
Multimedia applications have a high computational complexity, they have a regular and spatially local computation, and the communication between modules is significant. The quest for processors with increased processing power has lead to multi-issue CPU’s and speculative instruction pre-fetch strategies, which have driven the general purpose CPU’s far away from the energy lower-bound for the processing tasks to be performed.

Figure 2 shows the energy consumption for a single multiply-add instruction of several microprocessors over the last 10 years. Note that all processors lie in a range, which spans a factor of ten, with a few exceptions, which are actually low-power prototypes. The lower bound for the calculation of a multiply-add operation is shown in the left bottom by the line named 16x16 MAdd. The actual application gap is at least 40 for the 33MHz 5V Intel 486, 240 for the Motorola 68040 and even 700 for the first Intel Pentium processor. The trend is that even with better technology, the energy consumption to perform a single instruction increases.

![Figure 2: Energy consumption and application gap](image)

The factor 1000 increase of performance for the decade to come cannot be realised through an increase of the clock-speed with a factor 100 due to physical limitations.

The most common alternative to general-purpose computing is to use a full-custom design style. Application-specific coprocessors perform multimedia tasks more efficient - in terms of performance and/or energy consumption - than general-purpose processors. Even when the application-specific coprocessor consumes more power than the processor, it may accomplish the same task in far less time, resulting in net energy savings. The processor can for example be offloaded with tasks like JPEG and MP3 decoding, encryption, and some network protocol handling. An MPEG chip can handle video much more efficient than a general-purpose processor, but this option is getting less and less attractive. The main reasons are: the fixed schedule in the high-level synthesis, the related effect that the design is not scalable, and the costly design process which does not support any form of real-time prototyping. In our opinion this will lead to a rapid acceptance of a totally new design styles based on reconfigurable devices.
The difference in area and power dissipation between a general-purpose approach and application specific architectures can be significant. Full custom chips can be designed and manufactured at relatively low cost. However, this comes at the price of less flexibility, and consequently a new chip design is needed for even the smallest change in functionality or fabrication process.

A hybrid solution with application domain specific modules can offer the flexibility that allows the implementation of a predefined set of (usually) similar applications, while keeping the costs in terms of area, energy consumption and design time to an acceptable low level [1]. The modules are optimised for one specific application domain. Figure 3 shows three different approaches in the spectrum of hardware organisations.

We believe that the functional requirements of future mobile devices including the adaptability and flexibility of various system functions (both in terms of performance and energy) can be implemented using energy-efficient reconfigurable modules. Today there are commercially available Field Programmable Gate Arrays (FPGA). They operate as a field-programmable graph of 1-bit-wide lookup tables (LUTs) or CLBs [36]. It can be shown that the construction of an ALU from multiple 1-bit-wide lookup tables is energy inefficient. For a wide range of multimedia functions that use digital filtering algorithms on parallel data: video (de)compression, data encryption and digital signatures these devices do not possess the required processing power. For these functions 16/32 bit calculations (multiply, add) are required. We have experimented with a structure called FPFAs (Field-Programmable Function Array). These devices are reminiscent to FPGAs, but with a matrix of ALUs and lookup tables [36] instead of CLBs (Configurable Logic Blocks).

![FPFA Architecture](image)

**Figure 3:** The spectrum of hardware organisations [1].

**Figure 4:** FPFA architecture.
The instruction set of an FPFA-ALU can be thought of as the set of ordinary ALU instructions, with the exception that there are no load and store operations which operate on memories. Instead, they operate on the programmable interconnect; that is, the ALU loads its operands from neighbouring ALU outputs, or from (input) values stored in lookup tables or local registers. Hence, these devices use the locality of reference principle extensively. The graph-based execution of the FPFA is used to execute the inner loop of an application. The regular, general-purpose structure of the device makes a rapid context switch from one inner loop to another possible, hence on-the-fly reconfiguration. This is how a broad class of compute intensive algorithms can be implemented on an FPFA.

The FPFA concept has a number of advantages, for example:

- The FPFA has a highly regular, it requires the design and replication of a single processor tile, hence the design and verification is rather straightforward. The verification of the software might be less trivial. Therefore, for less demanding applications we use a general-purpose processor core.
- Its scalability stands in contrast to the dedicated chips designed nowadays, where it takes considerable effort to implement circuitry for tasks such as Digital Audio Broadcast and Digital TV. In FPFA, there is no need for a redesign of a scalable chip in order to exploit all the benefits of a next generation CMOS process or the next generation of a standard.
- The FPFA can do media processing tasks such as compression/decompression efficiently. Multimedia applications can benefit from compression by saving (energy-wasting) network bandwidth. This requires however an energy-efficient platform to perform the compression.

4.3.3 System decomposition

In a flexible system such as the MDC there are many trade-offs. Decomposition of system functions - such as the network protocol stack - and a careful analysis the data flow in the system can reduce the energy consumption considerably.

Applications that users run on a mobile need several functional resources of the system, such as processor, memory, wireless network interface, compression/decompression logic etc. In the CHAMELEON system we assume that such modules are programmable and can adapt to the demands of the applications and to the state of the environment, e.g. available bandwidth, bit error rate, available energy, etc. In general these modules are not independent and choices for the setting of one module may influence other modules. For example: when video has to be transmitted it can be compressed, which reduces the required bandwidth on the wireless network. However, more compression requires not only more processing power, it also needs better error-control. All these functional modules often have contradictory effects on the resources needed, and a trade-off has to be made to find an optimal solution. Not only the parameters can be changed, it might as well be profitable to migrate complete function from one module to another, possibly even to another machine. A complicating factor is that a wireless environment is very dynamic, it is not feasible to search for the optimal solution.

4.4 QoS driven operating system architecture

The operating system for the Mobile Companion has to deal with the peculiarities of the MDCs, their flexibility and adaptability and their energy restrictions. Applications for the MDC will be used in a variety of computing environments. Many applications are now designed for particular computing platforms like personal computers or set-top boxes or a specific hand-held, all with static performance. But in the MDC, applications will have to run in environments that differ dramatically in processor performance, communication performance and communication cost. Such applications will have to adapt their behaviour to the environment in which they run. This is a quite remarkable and new phenomenon; in the commodity QoS approach the application dictates the QoS and not the environment. The operating system will have to provide assistance for this adaptation, now called Quality of Service (QoS). This term stems from the notion that the quality of service an application can deliver depends on the resources that can be made available to it.

Traditionally, QoS is used in the context of network communication resources and systems resources needed for multimedia applications. In mobile-computing environments this notion of QoS has to be extended to all applications. An important issue is that all applications must be aware of energy
efficiency of a handheld multimedia device. Applications can deliver better QoS when the hardware they run on is in a higher energy state, but this might be a disadvantage for other applications. So there is a QoS trade-off between performance and battery life. Adaptability, flexibility and interoperability will be crucial for the entire system: from hardware components up to application programs.

We assume that there are several QoS managers, distributed in the global system. Applications might need resources under control of several QoS managers. The QoS managers then need to communicate with each other via a wired network and wirelessly with applications on mobiles. The applications/users send QoS parameters to a QoS manager. Possible QoS input parameters can be: application priority, performance parameters (bandwidth, latency, jitter, etc.), cost (energy, money (GSM ticks)).

The QoS manager tries to find a (near) optimal 'schedule' that satisfies the wishes of all applications. It computes 'contracts' for all resources with specific device dependent parameters: e.g. for a compression module the compression rate, for the display the video window size, for the network interface the bit/rate, the TDMA schedule or frequency band, etc. The QoS managers may have to communicate (negotiate) with the applications and with other QoS managers in order to find an 'optimal' solution.

Whenever a resource finds out that it cannot fulfil the contract it will notify the QoS manager. But it may also be possible that an application cannot reach the QoS manager any more because the mobile is out of range of the base station.

4.5 Embedding in research programmes
The project will be embedded in the Distributed and Embedded Systems group (DIES, Huygens), the Computer Architecture and Embedded Systems group (CAES), both of the Computer Science department; and the Network Theory Group of Electrical Engineering department. All three are participating in the Centre for Telematics and Information Technology (CTIT).

CTIT
The Centre for Telematics and Information Technology (CTIT) is a multidisciplinary research institute of the University of Twente, within the area of telematics and information technology. Six faculties of the university are involved in the institute's research, which means a total of 120 fte scientific staff and 20 fte non-scientific staff. The CTIT is one of the knowledge institutes within the Dutch "Telematica Instituut" (TI). CTIT co-ordinates the research of the Telematics Graduate School (TGS), and is linked to the European ICT research network called EUNICE. Research experiments within CTIT are carried out within the Advanced Networking Technology Center (ANTC).

The CHAMELEON project is related to the following CTIT research areas:
- Mobile and Nomadic computing
- Signal processing
- Architecture and implementation of digital systems

4.5.1 Distributed and Embedded Systems (DIES) (Prof. dr. Sape J. Mullender)
The DIES group within the Faculty of Computer Science of the University of Twente is responsible for research and education in the area of distributed systems and (real-time) embedded systems, i.e. on the borderline of software and hardware: design methodologies for computer networks, operating systems and robotics. The group addresses the following three themes:
- Multimedia
- Mobile computing
- Security

The group investigates the architecture, design and implementation of file servers for storage and archiving of multimedia data, operating systems that support the specific timeliness constraints of multimedia applications (soft real-time scheduling), and Quality-of-Service architectures that allow applications to adjust the quality of their presentation to the availability of resources. Mobile computing is addressed in by the Moby Dick project in various aspects ranging from energy-efficient architectures...
of the mobile computer and the wireless network interface, to Quality of Service architectures and applications.

The DIES group is and has been supported by a number of collaborative projects: Pegasus II, Esprit BRA 6586, 1992-1995, and Esprit LTR 21917, 1996-1999; Broadcast, Esprit BRA 6360, 1992-1995; CaberNet, Esprit No. E 6361, 1992-1998; Moby Dick, Esprit LTR, 1995-1997; Xerox Europarc, 1992-1996. The tele-working experiments are being supported by Stichting de Veur, a foundation that encourages innovative, serendipitous applications of IT; the tele-teaching experiments are being conducted in close collaboration with the University of Delft Institute for Telematics Systems Engineering.

Pegasus II (Esprit BRA 6586)

Multimedia applications of the future will involve the distributed processing of multimedia information in systems ranging from large servers, through workstations all the way down to “set top boxes”. The implementation of such applications will be greatly eased by the use of a common architecture providing application level Quality of Service, and, where possible, a common software platform even where the underlying hardware has diverse capabilities.

Pegasus II takes the results of the Pegasus I project as a starting point on which to build a complete distributed multimedia platform, including toolkits, user interfaces, filing systems and the emulation of familiar software environments. The work is based on the philosophy of the Pegasus project:

• Generic multimedia platforms, rather than single multimedia applications are the key elements of the “multimedia market” of the future,

• Communication and processing should be integrated,

• Resource management to provide application QoS guarantees is required.

The Moby Dick project

The Moby Dick project was a joint European project (Esprit Long Term Research 20422, 1995-1997) to develop and define the architecture of a new generation of mobile handheld computers [33]. The design challenges were primarily the creation of a single architecture that allows the integration of security functions (e.g. payment), externally offered services (e.g. airline ticket reservation), personality (i.e. these devices know what their owners want), and communication.

The experiences and results of the Moby Dick project and the Pegasus project will be used in the CHAMELEON project.

4.5.2 Computer Architecture and Embedded Systems (CAES) (Prof. dr. ir. Thijs Krol)

The CAES group aims at formal design methods for hardware systems. The research in the CAES group is divided into two projects, i.e.:

• The TRADES project (TRAnsformational DESign), with main emphasis on description methods which support the correct design of digital systems and which will make it possible to derive the desired system properties from the system description; design and synthesis methods which support both the correct and optimal design of digital systems. A central role in this area is taken by the hardware description language VHDL and the Sprite Input Language SIL, an intermediate between hardware description languages and silicon compilers.

• The FADE project (FAult-tolerant DEsign), with main emphasis on: methods for maintaining system functionality in the presence of malfunctioning hardware (fault-tolerant and dependable computing).

4.5.3 Network Theory group (prof. dr-Ing. O. E. Herrmann)

Subject of the research and of the courses of the group is the automatic design of digital information processing (VLSI) systems. In addition, the aim is to further extend the theoretical basis in the fields of signal- and image processing, in the field of neural computing, and in the field of VLSI-design. The attention focuses on the development of CAD methods for analysis, simulation, synthesis and
verification of VLSI-systems, and the development of methods for realisation of reliable electrical circuits.

Application areas of interest are:

- acoustics,
- medical image processing,
- handwriting recognition and
- mobile communication.

An active co-operation with the Philips research labs has resulted in several projects on the use of DSP in acoustic signal processing applications, including mobile applications and applications in museums, to name just a few. The co-operation resulted in the appointment of Prof. W. F. Druyvesteyn in the S&S-NT group. High performance / low power computing is another major area of interest covered by the group in co-operation with Philips Medical Systems, Philips Research labs, Hollandse Signaal apparaten and other groups in the area of signal processing. The area of Neural-computing gets special attention in co-operation with for instance Nedap Groenlo and others. A complex medical imaging system has been developed in co-operation with an American industrial partner (Lunar). In co-operation with the Dutch Telecom Police and TeleDanmark in Copenhagen the new cellular digital wireless transmission standard, called TETRA (TErrestrial Trunked RAdio), is investigated and tested. Very successful courses have been taught for industry in the area of digital signal processing.

4.5.4 Philips Research groups/sectors

The following groups/sectors will participate in the project:

**IST:**

The Information and Software Technology (IST) sector of Philips Research Laboratories in Eindhoven provides advanced software solutions for a large variety of industrial problems. The ongoing digitisation and the advent of programmable hardware make it attractive to realise increasingly more functions in software for these programmable devices. IST’s aim is to do this effectively and efficiently for the whole range of Philips products, both consumer and professional ones.

**IC-Design Centre:**

The sector IC Design develops know-how and transfers this to the Product Divisions of Philips. The aim is to participate and contribute to the main innovations in Philips, linking the work on design methodology to innovations in systems and technology.

4.5.5 Lucent Technologies WCND

The Wireless Communications Networks Division (WCND) of Lucent Technologies is located in Nieuwegein. Its WaveLAN product range is a world-leader in terms of performance and market volume. In order to secure its leadership “WCND” needs access to academic research and needs to be able to hire qualified staff trained in the peculiarities of wireless technology.

The Chameleon project supports both objectives and therefore it is relevant to the broader perspective of Lucent’s wireless business in general and in particular that of “WCND”.

The main areas of interest for “WCND” are power efficient digital signal processing and power efficient protocol execution and performance of related tasks. The area of reconfigurable systems embeds both of the above specific areas in a broader context and therefore also merits significant attention.

4.6 Scientific relevance

This proposal addresses fundamental issues in the architecture and design of low-power hand-held multimedia systems, with particular emphasis on energy conservation. Personal mobile computing will play a significant role as a driving technology in processor design. Neither contemporary architectures nor state-of-the-art technology can provide the wealth of services required by a fully functional mobile multimedia computer. The increasing levels of performance and integration that is required will be accompanied by increasing levels of energy consumption. Without significant energy reduction...
techniques and energy saving architectures, battery life constraints will limit the capabilities of a Mobile Digital Companion. Recent research shows that a radical new approach has to be taken in order to fulfil the requirements - in terms of processing power and energy consumption - of future mobile applications. A primary goal of this project is to prove that a reconfigurable systems architecture in combination with a QoS driven operating system can deal with the inherent dynamics of a mobile system. A novel aspect in this concept is that chip design is replaced by dynamic reconfiguration and reprogramming. In our opinion, this sheds a new light on the fundamental issues of low-power embedded systems.

In this project we will develop new concepts, architectures and generically applicable protocols to enable the development and utilisation of a flexible and reconfigurable systems-architecture for mobile multimedia systems.

The research in this project will provide a number of important scientific contributions.

- The development of novel reconfigurable architectures (FPFA) that provide an energy efficient solution for many multimedia and digital signal processing applications.
- The development of models and techniques to allow a high-level problem specification for diverse multimedia applications, including the development of analysis and synthesis tools for application and system development.
- The definition and development a hierarchical - QoS based - model of the whole system (covering the architecture, communication, distributed processing, and applications).
- The definition of a model of energy consumption at various levels of abstraction of all the system-level components of the architecture. Using this model the inherent trade-offs between e.g. performance and energy consumption can be evaluated and a proper adaptation of the whole system can be made.
- The development of new techniques and methods for a QoS driven operating system to deal with the inherent dynamics of a mobile system. They should offer clarity in the way in which applications and systems can utilise the reconfigurability of the system.
- The research enables the development and deployment of energy-efficient handheld systems that have the flexibility to handle a variety of multimedia services and standards, and have a short design cycle time.

4.7 Approach: methods and techniques

The above-mentioned goals can be achieved by carrying out research on a number of important themes that will be prevalent in the future mobile world. The themes that will be addressed are: reconfigurable computing, energy efficiency, mobile multimedia computing, Quality of Service architectures.

CHAMELEON is a systems project whose general approach is experimental. Design and implementation of test-beds of the system and the applications are the primary methods to evaluate the architectural and systems solutions proposed in the architecture. New techniques will be tested and judged by means of experiments. Working with real-life and realistic problems in the application domain, including new ways of handling reconfiguration in various levels of granularity is considered of great importance.

In CHAMELEON project the test-beds will be based on both commodity and research hardware/software. These test-beds will be made to demonstrate the suitability and effectiveness of our approach. Depending on the first results of this project and the available funding and support from industry we might extend this project by designing a full-custom FPFA prototypes. We will focus on solutions beyond the horizon where no commercial market exists yet, as well as on contributing to the development of new theories and architectures. A unique characteristic of the proposal is in the integration of competence and ongoing projects from the area of distributed systems, mobile computing, VLSI design and wireless networks. Thus, CHAMELEON is in a position to form an orchestrated research attack on developing more effective system architectures for the masses of MDCs.

4.8 Related research groups in the Netherlands
The project is performed within the CTIT and has links to a number of other research projects and institutes.

4.8.1 CTIT project: Internet Next Generation project.
The subject of this project [9] is the development and introduction of Quality of Service (QoS) mechanisms for the Internet. The specific mechanisms that will be investigated are integrated services and differentiated services; within this project they will look at core networks as well as wireless & mobile access networks, which form potential QoS bottlenecks because of their scarce resources. To improve QoS, the project will also investigate new approaches to Internet management and Internet accounting. We have a direct working relation to work unit 4: QoS over wireless and mobile access networks.

4.8.2 Telematics Institute (area Mobile and wireless services, sub-project MOSIS)
The objective of MOSIS (MOBILE Services for the Information Society) is to determine the future market for mobile and wireless services, to identify the most important future generic services and to define characteristics of future mobile and wireless services and underlying networks in order to match requirements, imposed by future mobile services, with the properties of wireless networks [10]. Because these services will also become important for future mobile devices, we will follow the results of the project with interest.

4.8.3 Ubicom project TUD
The objective of the Ubiquitous Communications program [11] is to contribute to the extension of the functionality in wireless communication of a mobile person. The program's scenario is a campus-size wireless network providing to the mobile user broadband information exchange functionality. The focus of the program is on hands-free visual communication with agreed measures of reliability, quality, synchronisation and real-time performance. The ubiquitous communications scenario and focus have several issues to which the projects in the program pay attention. They are: the processing and displaying of moving pictures in a light-weight, low-power, head-up transceiver; the communication through high frequency, bi-directional wideband, multiple access links; the emulation and performance analysis of the overall communication system; and the manipulation and compression of virtual reality and real-life image sequences.

We have contact with several researchers of the project, among others the project leader dr. ir. Ed Deprettere and prof. dr. Henk Sips. This contact might lead to a future joint project proposal. We have agreed to exchange hardware and software modules that are and will be developed by the mutual projects.

4.8.4 Mobile Multimedia Communication (MMC) project TUD
It is a multi-disciplinary research project on Mobility and Multimedia. Present systems force the user to make a choice between mobility and multimedia [12]. The MMC project started in April 1996 to find out new ways for presenting the user the combination of mobility and multimedia. It enables professionals on-the-move to work with higher quality and greater efficiency.

4.9 Related international research groups
The project is related to many projects concerning mobile computing and reconfigurable computing. The following subset indicates those projects that in particular are related to the project.

4.9.1 Infopad University of California, Berkeley
The goal of the InfoPad research project was to develop the hardware, software and mobile network support which will allow ubiquitous, wireless access of real-time multimedia data from high speed networks using an inexpensive, portable terminal. It in effect is a “network terminal”, but with the additional capability of portability.
4.9.2 **Pleiades: Ultra-Low-Power Hybrid and Configurable Computing, University of California, Berkeley**

The objective of this project is to develop a family of ultra low-power programmable processors for embedded applications, such as encountered in communications, portable multimedia, data acquisition and display, and space applications [2]. Demonstrate that very low levels of power (energy) dissipation (mW range) can be obtained through the use of single-chip reconfigurable hybrid multiprocessors of mixed granularity. Develop a complete design methodology to support both development and programming of the reconfigurable processors.

4.9.3 **Reconfigurable computing, Department of Computing at Imperial College, University of London**

The research interests of this group includes: architectures, design methods, languages, tools and models for custom hardware, parallel computers and embedded systems, particularly those involving reconfigurable devices such as field-programmable gate arrays, and their applications in areas including machine vision and sensor processing for biomedical and industrial systems [13]. They are currently focusing on theory and practice of run-time reconfigurable architectures and library-based compilation techniques. Ties Bos has been visiting this group for four weeks and they are interested in a future co-operation. Currently we are using a hardware module (Riley2) with several Xilinx FPGAs designed by this group. This board was donated to our group.

4.9.4 **Xilinx - Virtex**

The Virtex family of Xilinx is a new generation of FPGAs with a high density and high performance. Virtex series devices are partially reconfigurable and their size range from 50,000 to 1,000,000 system gates at clock speeds up to 160 MHz [14]. In a prototype we might use the new Virtex components.

4.9.5 **Medea**

Medea A-222: COMPORT: COMponents for PORTable multimedia systems.

Main challenges in this project are:

- to deliver the technical solutions needed when new portable multimedia systems will be defined in the future.
- to focus on silicon integration keeping in mind the upcoming necessity of a huge functionality, combined with the high demands of the very critical consumer in the future
- to design in very low power consumption, also inducing environmental advantages

Partners in this project are: Philips Research, Fraunhofer Institut fuer Integrierte Schaltungen (FhG IIS-A), Robert Bosch GmbH, Philips Semiconductors, CNET, Philips Consumer Electronics, STMicroelectronics, and Thomson CSF.

4.9.6 **OFFIS: Universität Oldenburg**

The research activities of the group are concentrated on two fields in the design of microelectronics, at present both of immediate interest.

- Reduction of power consumption of integrated circuits
- Object-oriented description of hardware systems

Both themes are part of the circle of problems called "Design of Embedded Systems" which, at the same time, is one of the main research domains of the Research Institute OFFIS. Due to a close co-operation of the VLSI-design unit with the respective main research domain of OFFIS, the research elements worked out at the University can be implemented in application-oriented projects in OFFIS. An extremely close co-operation between the University and OFFIS is shown by the opportunity of going ahead with studies works and theses in connection with OFFIS projects.

4.9.7 **IMEC**
IMEC performs scientific research, which runs 3 to 10 years ahead of industrial needs, with a view to practical applications. The R & D activities are concentrated on:

- The development of novel design methodologies for monolithic as well as multi-chip systems and ATM
- The development of processing technologies for the next generation of ULSI chips, micro-systems, sensors, solar cells, multi-chip modules, optoelectronic components
- The support of the training of VLSI design engineers on behalf of both educational institutes and industry

4.9.8 Distributed Multimedia Research Group: University of Lancaster UK

Mobile multimedia computing research focuses on the development of advanced mobile applications and their supporting infrastructure. Such applications typically involve peer-to-peer and group communication of distributed multimedia and time/safety critical information and make significant demands on their communications subsystems, stretching many wireless networks to their limit. Lancaster is now widely recognised as the UK's premier centre for mobile computing research and has an outstanding track record in this field.

Future environments will consist of a heterogeneous mix of wired and wireless networks and end-systems. Of particular interest to the group are the difficulties of developing and supporting applications, which can operate in, and take advantage of, this diversity in infrastructure. To this end all of the projects at Lancaster encompass the notion of reactive or adaptive behaviour whereby applications are able to tailor their behaviour in response to changes in the level of service being provided by their underlying support infrastructure.

To provide distributed systems support for mobile applications we have extended a number of common distributed systems platforms as well as developing our own state-of-the-art high-performance asynchronous platform with integrated support for QoS information and mobility.

5 Utilisation

Small portable computers with a smart card and communications device can replace cash, cheque book, passport, keys, diary, phone/pager, walkman, radio, maps, etc. They can be used as multimedia terminals to watch a video fragment, to listen to your favourite music as a digital walkman or to take a picture with the on-board camera. In addition, these devices will be used as means to participate in an on-line information community. The combination of networking, security and mobility will engender many new applications and services. Not only do they provide the means for users to stay in touch while on the move and to receive notifications of important events, it also gives people a whole new way to interact with the infrastructure of large public institutions, such as interactive class-rooms, airports, supermarkets, or even whole cities. For example: standing in line for ticket or teller windows may become a thing of the past. Instead offices and public places will be equipped with access points, through which hand-held computer users will be able to communicate with the existing infrastructure. The Mobile Digital Companion will create a universal platform for the wireless multimedia communication and with it, numerous potential areas of use:

- mobile data recording and information systems (doctor in a hospital, logistics on a building site, city or museum guides, etc),
- mobile audio and video communication systems,
- wireless machine control.

The combined functionality of a Mobile Digital Companion engenders many new types of applications, such as environment aware control, digital chequebooks, multimedia document players, mobile Internet terminals, paging, and an automatic diary that keeps track of where you were and with whom. In this
project the university will co-operate with leading industry to get a better insight in the opportunities and fundamental problems of these new applications, low-power mobile embedded systems, personal machines and the infrastructures needed.

The results of the project will be models, concepts and methods for flexible and reconfigurable architectures and demonstrators for the Mobile Digital Companion. The demonstrators will be related to wireless multimedia applications. The development of a 2 Mb/s pico-cellular network based on UMTS is considered as being a suitable demonstrator of the concept. The development of a H.263 videophone using a USB camera and a LCD screen is another candidate. By building such demonstrators we are able to gain inside information in the real problems when building such systems.

The results that will be obtained in this project will advance the state-of-the-art knowledge on embedded systems and software, and will develop a better understanding of low-power hand-held multimedia devices. It will strengthen the co-operation between industry and academia and will improve the market position of Dutch industry.

We will have both internal exploitation by building up strategic competence and synergies with other research projects, commercial exploitation, product development and patents on the developed concepts and protocols, as well as external exploitation by publishing papers in the scientific community, internal and external reports, all available on the Web. The results will be disseminated continuously through scientific publications in workshops and seminars, at international conferences and in journal papers and by other collaborative projects in the Netherlands and Europe. To promote the dissemination of the results a public workshop will be organised each year.
6 Literature related to the proposal


[9] Internet Next generation see http://ing.cit.utwente.nl.


7 Recent publications related to the project


[56] Rem, F: “Power Estimation for High-Level Synthesis.”, University of Twente, Laboratory for Network theory, 1997, March 06.
[57] Remmelink, G.B: “Design of an Architecture for a Field Programmable Function Array” University of Twente, Laboratory for Network theory, 1997, June 01.


8 References to products and patents


