Research Center “Ambient Intelligence” at the University of Kaiserslautern

Lothar Litz, Norbert Wehn, Department of Electrical and Computer Engineering,
Bernd Schürmann, Department of Computer Science,
University of Kaiserslautern D-67653 Kaiserslautern

Abstract

Ambient Intelligence (AmI) has become a keyword for companies, research centers, universities, and for European programs in Information Technology. AmI stands for a new paradigm how to use the possibilities provided by the fast-paced development of microelectronics and how to develop the Post-PC era in such a way that an enhanced quality of life for human beings results. One year ago the research center “Ambient Intelligence” was founded at the University of Kaiserslautern and started work with an interdisciplinary group of researchers out of five different faculties. They define the Kaiserslautern way of AmI which is demonstrated in this article.

1 Ambient Intelligence

In 1988 Mark Weiser of Xerox park presented the visionary concept of “ubiquitous computing” which he named the third wave in computing or Post-PC era [1]. Steady progress in microelectronics driven by Moore’s law, microsystems, software and communication technology makes this dream to come true and evolved into the world of ambient intelli-

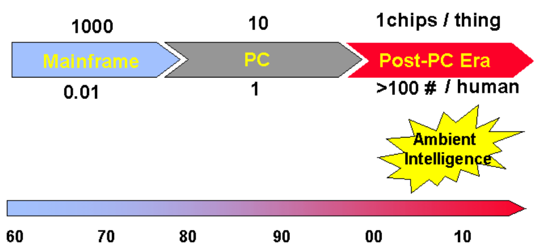

Figure 1 : Post-PC Era

gence (AmI) [2, 3, 4]. Figure 1 presents this evolution. In the 60s a main frame computer was based on several 1000 components and only accessible for very limited number of humans. This age was dominated by data-processing applications.
Nowadays computing systems are composed of a few chips. Advanced signal processing, multimedia and networking applications are the driving applications. In the future all aspects of communication and computation can be implemented as system-of-chips on a single die. AmI is a new type of information technology and is fundamentally different in that technology recedes in the background and puts the human being to the foreground i.e. it adapts to the people instead of the other way around. AmI systems are electronic systems are electronic environments that are sensitive and responsive to the presence of people. Hence, the user is surrounded by invisible computers which communicate seamless with each other. Users interact with these environments either directly through natural modalities such as speech, gesture, and tactile movements or in an indirect way by many low cost sensors in the clothes and in the human environment. AmI systems are

- *embedded*: they consist of many invisible distributed communicating devices,
- *context aware:* they know about their actual state,
- *personalized:* they can be tailored towards the people needs and can recognize them,
- *adaptive:* they can change in response to a person and his environment,
- *anticipatory:* they may anticipate the desires.

The primary goal is to improve the quality of life, covering different areas like recreation and sport, health and security, working, care for elderly people and entertainment, to name just a few of them.

AmI is composed of *ambient* and *intelligence*. The realization of the “ambient part” already implies many challenges, but even more challenges are imposed to the “intelligence part”. Thus the development of AmI systems requires a real interdisciplinary cooperation between various scientific communities: sociologists, psychologists, computer scientists, communication and network specialists, microelectronic experts, control engineers, and system architects. AmI is vision driven and demonstrator vehicles are of great importance to identify the challenges, to promote the interdisciplinary, and to

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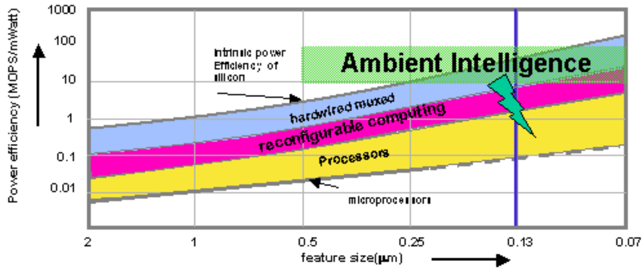

Figure 2: Energy-Efficiency

get insights into the interdependencies of the various disciplines of AmI systems [9].

In the following we will discuss some challenges related to the "ambient part" [2,3,4,5]. Due to the limited space we focus on some of the problems.

AmI systems are heterogeneous dynamic networked systems of embedded devices. Applications are distributed and of dynamic nature, too. Communication requirements range from few bit/s to several Gbit/s, computational requirements from some kop/s to several Top/s and the power requirements from microwatt to watts. Developing dynamic networks and embedded devices which cover several orders of magnitude in performance, communication bandwidth and power are a challenging task.

The basic implementation technology of AmI systems will be silicon CMOS. Combined with System-in-package techniques, a huge amount of integration possibilities exist. Besides these technology issues, system architects are faced with the challenge to find system architectures (software and hardware) matching these integration possibilities and the special needs of AmI systems. As mentioned above AmI systems have to provide adequate performance and energy efficiency under widely varying conditions in a dynamic environment. Hence, AmI architectures have to provide scalability and flexibility, both during development (i.e. programmability) and in-field (e.g. reconfigurability). But flexibility contradicts energy-efficiency. Figure 2 compares different architecture styles w.r.t. power efficiency which is defined as MOPS/mw [2]. From this Figure we see that the power efficiency in state-of-the art technologies requires hardwired dedicated solutions. Programmable solutions have an efficiency which is 2 orders of magnitude too low. Thus, energy-efficient system design and energy-efficient wireless communication are keys for AmI environments.

To face the problem of scalability and improved power efficiency, AmI systems are layered architectures i.e. they are based on different types of nodes with various communication bandwidth, signal processing capabilities, and power constraints, respectively. Typically, three node types can be found.

Devices on the lowest level – butterfly level based on microwatt nodes – form highly integrated wireless sensor networks and are used to gather information from the environment. Power and footprint constraints are the most stringent constraints for these devices. Thus, communication bandwidth (in the order of kbit/s) and signal processing capabilities (some kop/s) are very limited. These sensor networks often contain redundancy which can efficiently exploited for power optimization. A typical part of this type of network is the MICA node [6].

Nodes on the next hierarchy level – hummingbird level based on milliwatt nodes – provide higher communication bandwidth, computational power (e.g. DSP and/or ARM functionality), and memory. Power efficiency, low-cost, and small sizes are also mandatory. On this level, data gathered from the sensor networks can be processed and evaluated. Optimum communication bandwidth, reliability, security, and range are a very important issue. Many communication standards exist which range from e.g. short-distance point-to-point technologies like Bluetooth to 3 G mobile phone systems. Wireless LAN technologies are filling the gap between these two standards and are a good compromise between bandwidth requirements and environmental constraints. However, looking at the cost and size constraints, WLAN cards are too expensive and too large to allow true ubiquity. A first step for higher integration and more power efficiency is the TNETW1130 chip from Texas Instrument which is a single chip MAC and baseband processor supporting all versions of the IEEE802.11 [7]. However, standardized wireless communication protocols have an inherent inefficiency due to excessive generality (for example, the MAC layer of the 802.11 standard has a channel reservation and acknowledgement mechanism which requires four transmissions for each actual data packet to be sent). In general systems, communication middleware and MAC layer as well as applications are fundamental sources of inefficiency especially w.r.t. power efficiency. Thus, keys for power efficient networks are

- energy efficient communication software which takes the underlying hardware into account,
- energy availability which allows an adaptation of energy consumption in response to changing environmental conditions.

I.e., the communication system uses just the energy which is necessary to provide the required communication quality. A power aware middleware layer has to link communication quality and computation power with hardware energy consumption. Well known techniques like dynamic voltage scaling and scheduling can be used to adapt the throughput of the signal processing units to the needs. Adjustable power amplifiers can be traded versus use of for-

ward error correction codes. These are just a few of the different optimization knobs to be managed by this layer.
Nodes on the highest level – workhorse level – can have high-speed fixed network backbone and provide large computational power. Energy and size restrictions are relaxed since these nodes are typically stationary. "Intelligence", the second part of AmI, needs a huge amount of computational power. E.g. the recognition of faces under different poses and illuminations requires Top/s. Thus, building awareness intelligence and sophisticated user interaction has to be performed on this level.

2 AmI Research Center at Kaiserslautern

Ambient Intelligence has become a rapidly growing research discipline. Many groups and institutes now move their interests towards this direction. In most cases, these are groups working in related disciplines which now enhance their scientific work with AmI questions. However, the major part of these groups considers a fraction of AmI that is related to their scientific domain, only.
On the other hand, AmI in its full broadness is a very much interdisciplinary research topic. As we stated above, it needs comprehensive cooperation between sociologists, psychologists, computer scientists, communication, control and network specialists, microelectronic experts, system architects, and so on [9].
Our AmI research center at Kaiserslautern has been established as such an interdisciplinary team. Although some members of the research center belong to the leading scientists in their own community the real strength of our AmI research center lies in its interdisciplinary orientation. Twelve research groups out of the five faculties

- Electrical and Computer Engineering
- Computer Science
- Social Science
- Mechanical Engineering
- Mathematics

form our research center. Six AmI topics are addressed by two or more groups, each:

- *Human orientation*
  Three groups are working on topics like human machine interface, usability, and human acceptance of technical systems.
- *Sensors*
  AmI is very much based on a comprehensive sensor network consisting of simple, cheap, and unobtrusive sensors. New sensors might improve the applications drastically.
- *Communication*
  Besides intelligent processing of all those sensor data, a central part of AmI systems is seamless communication via wireless ad-hoc networks.
- *Control*
  Feedback Control over different layers is an essential component of the AmI-System Intelligence. But it needs new methods to cope with the problems of networked control systems basing on ad-hoc-networks with the multiple restrictions.
- *System architecture*
  The various facets of AmI require a highly dynamic system architecture (hardware and software). Especially the interface between the hardware components and the application software is very important.
- *Application*
  The "intelligence" part of an AmI system is located at the application level and therefore depends very much on the given scenario. One example will be shown in the following section. The discussion of scenarios and the development of demonstrators also play an essential role in the process of understanding each other in the interdisciplinary researcher team and finding the many trade-offs between neighboring problems.

3 Current Scenarios and Demonstrator

3.1 How to choose good scenarios and demonstrators

All research groups described above have to work in a common direction. In addition to the general research questions of the different disciplines, AmI defines further challenges regarding technology and application. The most important AmI challenges have been described in section 1.
Obviously, vision driven AmI research needs adequate scenarios and demonstrators. Different scenarios imply different challenges to the various research disciplines. While some scenarios are challenging for one scientific community (but minor interesting for other communities) other scenarios behave totally different for that aspect.
In the recent past, our AmI research center at Kaiserslautern did a lot of work in studying different scenarios. A good scenario has to meet the more the better the following requirements:

- It must be challenging for multiple research groups.
- Expected research results must be generic and transferable to other domains.
- The scenario has to allow designing demonstrators and experiment platforms which are feasible in our environment and budget.

- The application should be easily understandable or domain experts must be easily accessible.
- It should not be a just-for-fun-scenario, but should rather be intended to really enhance the quality of life in a serious discipline.

Among the scenarios we studied in the recent past the three "assisted"-scenarios [8] have been ranked first:

- **assisted living**, e.g. support of elderly people and people in rehabilitation,
- **assisted training**, e.g. for (semi-) professional bicycle training groups.
- **assisted working**, e.g. future human centered manufacturing and paperless electrical field installation,

While we are interested and working on all three scenarios we found out that the second one meets most of our requirements regarding a good scenario. In the following subsections we will first describe a typical scenario of that domain as well as a demonstrator we are developing until end of this year. After that, we will show how the scenario fits to the requirements described above and to the requirements of the groups of our research center.

3.2 Scenario "Assisted Bicycle Team Training"

The AmI system shall assist a racing bicycle group of 2 … 30 cyclists. The objective may be optimizing the training effect for the group or testing different strategies to win a race. Each cyclist has his own profile and training plan. The AmI system has to plan and control the training tour in such a way that each group member will meet his training plan as far as possible. This objective is very much situation dependent.

Background

Cyclists with different conditions and strengths can ride together within a training group because weaker cyclists can exploit lee. Headwind mainly slows down the leader of a group while all other group members need less pedal power and energy within lee. This effect increases with higher speed of the group. The power and energy saving depends on the group formation and the direction of wind, too.

Cyclists will tire differently. The current physical condition of a cyclist has impact on different medical values which can be measured by sensors. Today, that condition can be estimated by his heart rate and his pedal power (i.e. the power he is riding the bicycle). As a rule of thumb, more pedal power while low heart rate indicates a better constitution. Additional sensor types may yield better estimation of the physical condition.

Cyclists have different abilities. They prefer different track sections. One cyclist might be better in riding uphill, another one might be stronger on plain with strong headwind, and a third one might be skillful in riding downhill or on a twisty road. There may be more differences.

The AmI system has to plan and control foresighted and it has to react to situational changes adequately. This requires an intelligent support of human beings by more than an ordinary control strategy.

System Requirements (Scenario)

Today, the system's task is done minor optimally by a trainer who knows the overall ability of the cyclists but not the actual situation in detail. There is much space for improvement by an AmI system.

In our scenario, each cyclist has an individual profile (ability, maximum heart rate, health state, cycling qualities regarding the current track section, overall strength, etc.) and a training plan consisting of a schedule of objectives for the current training tour. The AmI system which is based on various sensors (e.g. heart rate, pedal power, wind, position) has to control the formation and speed of the group so that all cyclists will meet their actual training goal as good as possible.

Depending on

- the track profile,
- the group's current position on the track,
- the speed and direction of wind,
- the physical condition and state of exhaustion of all cyclists,
- the cyclists' profiles and training plans,

the formation and speed of the group should be optimized to improve the training effect of all cyclists. Each cyclist will be directed to an exact position in a selected formation. It will be assumed that all cyclists will take in their designated positions (if this is possible) but this cannot be guaranteed. As there is typically no sensor detecting the actual positions of the cyclists, detecting the actual formation of the group is another challenge for the system.

The AmI system provides each cyclist with situational personalized data (e.g. whether a cyclist is the leader, the trainer, or within exceptional situation). The type of data which will be displayed also depends on the available hardware (while today's 4 bit bike computers can display the few most important numbers, only, a modified PDA might be able to display the track profile in a graphical manner).

Communication within the sensor network of a single bicycle as well as between bicycles is wireless with limited communication range and one of the AmI specific challenges in the technology field. Intra-bicycle networks of closed-by bicycles will disturb each other. Congestion control of dynamically changing low-bandwidth networks becomes an important aspect. In addition, transmission errors, message loss, and interceptions due to group splitting may become essential in such an environment.

3.3 Demonstrator

One advantage of the bicycle scenario is that it meets the requirement of easily developing demonstrators and experiment platforms.
In our research center, we started to develop a demonstrator that can be used outdoor ("real-life demonstrator") as well as indoor ("virtual reality demonstrator"). The outdoor variant will be very similar to the indoor variant. Here we will concentrate on the latter one. For the indoor demonstrator four bicycles are mounted to wheel stands (ref. indoor cycling training) and are attached to a simulation computer (see fig. 3). This simulator, in combination with a screen and the braking force of the wheel stands, replaces the environment of the real-life demonstrator. By adapting the braking force individually for each bike, cyclists with totally different physical conditions and strengths can use the demonstrator together. A smart simulator control can inject test patterns for a large number of experiments.
Each bicycle has several sensors which are connected to a central bike computer via cable or wireless communication. At least, all sensors attached to the cyclist (human being) need wireless interfaces. Several bicycles (at least one in the group – but not all) are equipped with GPS.
Our demonstrator will have a hierarchical wireless network (ref. Section 1):

- Intra-bicycle network (sensor network based on microwatt nodes and low-power communication: Zigbee and "below")
- Inter-bicycle network (milliwatt nodes with WLAN-like communication)
- Possibly long distance network (watt nodes communicating e.g. via GSM).

The intelligence part will be implemented at the two upper levels with a powerful watt node realized on any GSM-port computer, may be in an accompanying car or anywhere else.

3.4 AmI Relevance

For our AmI research center, the main advantage of this scenario and demonstrator is that it covers many different research questions which are typical for AmI. It covers the "ambient" part as well as the "intelligence" part of AmI which have been described in Section 1.
Some major AmI research aspects concerning the ambient part are

- *Human-computer interface / usability*
  As described above, the user interface has to be situation- and role-based. Cyclists may have different roles (e.g. leader, trainer) and interests. Exceptions (e.g. health monitor, too much headwind) must be covered. The dynamic integration of many different and new device types (e.g. glasses with display or bike helmet with microphone and speakers) requires the development of new device models as well as tailored code generation and dynamic loading of code.
- *Sensors*
  Sensors should be simple, cheap and lightweight. The sum of many coupled simple sensors for various physical values should result in more information than we have today by current expensive stand-alone systems. Our sensor group is working on new sensors which need to be small, lightweight, wearable, unobtrusive, and robust. Newly developed sensor types can improve the application.
- *Dynamic communication network*
  A central aspect of the scenario is a tailored wireless dynamic ad-hoc network based on different technologies. Subnetworks of a hierarchical communication system (BAN, LAN, WAN) may disturb each other drastically. Communication channels will vary all the time because cyclists vary their formation all the time, too. Multi-hop routing is a topic in the same manner as splitting and re-connection of (sub) networks.
- *Dynamic system architecture*
  The variable hardware platform requests dynamically changing system architecture. For instance, functions which are located on a powerful PDA mounted on the handle-bar during training (e.g. due to dependability reasons) must be moved to a remote computer during race because cyclists then use small, lightweight cycling computers, only.
- *Technology constraints*
  Our scenario covers almost all technology constraints which are related to AmI. On the one hand, we need a dynamically changing hardware platform (e.g. totally different processors and user interfaces, plug&play of sensors) and software structure. On the other hand, we need low power (all subsystems are powered by small batteries, solar cells, or other innovative energy

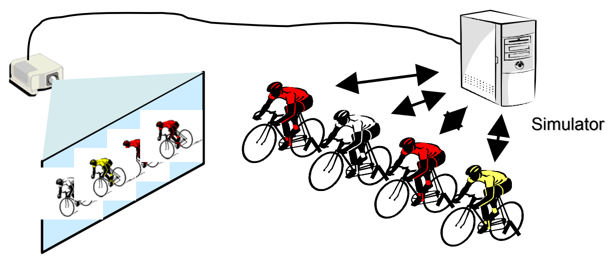

Figure 3: Indoor demonstrator

sources, resp.), restricted size (hardware devices including sensors are mounted on the bicycle or cyclist), and weight (for racing cyclists each gram counts).

Regarding the intelligence part of AmI our scenario covers e.g. following topics:

- *Human orientation*
  First of all, our AmI system supports human activities. The system has to adapt to cyclists' activities and condition so that it needs situation- and location-based functions (the goal depends on location, physical condition, trainer, etc.).
- *Intelligent control*
  The AmI system has to control a dynamically changing group of human beings. The control strategy depends on the situation, the actual track profile, and the physical condition of the cyclists which has to be estimated. To improve the performance of the system learning from the rides may also be possible. Last but not least the control strategy is coupled with the user acceptance.

The bicycle scenario meets the other requirements for a good scenario, too. Basically, it is easy to understand. For a deeper insight we have access to trainers of bicycle racing teams, training scientists, and sports physicians.

Furthermore, our scenario is of interest in the bicycle training domain. Many trainers are interested in having such a training aid. We also believe that our solutions may be worthwhile for future cooperation with industry.

Finally, it has many bridges to other domains, so that the solution for the bicycle scenario will solve related problems, too. Some related research disciplines are

- *Assisted living*
  One major aspect of assisted living is health monitoring. This has relations to our scenario, already. However, the scenario can be extended towards monitoring bicycle riding patients with cardiac troubles. In such a scenario, the system has to watch the maximum heart rate, too. Many sensor systems would be the same in both scenarios.
- *Assisted working*
  Two major AmI aspects in assisted working are location-based services and dynamic integration of new sensors/devices. Both aspects will also be found in the bicycle scenario. Human models describing the behavior of people and interaction with human beings are important for both scenarios.
- *Car communication*
  Although the bicycle scenario has different objectives there is much overlapping with car communication scenarios. In both cases we have a moving group of individuals dynamically changing their formation all the time and exchanging information to meet a global goal.

4 Conclusion

The comprehensive description of the bicycle scenario has shown that Ambient Intelligence is able to revolutionize life disciplines like sport training e.g.. Ambient technology and intelligent system behavior will support human beings even in non-technological domains.

There will be solutions for the ambient and for the intelligence part which are generic and can be transferred. To find these solutions only one way is possible: Teams of interdisciplinary researchers have to work together, starting with understanding each other in an adequately deep discussion. Scenarios and demonstrators are the only vehicles to make sure this understanding and to define and to solve the open problems.

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