Creating a World of Smart Re-configurable Devices

Extended Abstract

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Abstract. We often hear the world is evolving towards ambient intelligence. Is this another buzzword like artificial intelligence with which it shares the abbreviation AI? What are the properties of ambient intelligence? What will be needed from a technological point of view? Electronic devices in an ambient intelligent environment should combine power efficiency with run-time flexibility. These are conflicting requirements. Re-configurable devices could be an answer, but what should be their properties?

1 A View into an Ambient Intelligence Future

Let's have a look at electronic devices as I expect them to be available in 2010. In sports, athletes, for example runners, will have sensors all over their body, measuring blood composition, electro-cardiogram, electro-encephalogram, breathing condition, motion, stress and position of the joints, etc. These smart sensors will contain the actual solid-state sensing device, analog conditioning circuitry, digital signal processing and RF interface. Using a wireless Body Area Network (BAN), they continuously transmit their measured data to a Wearable Digital Assistant (WDA). The WDA does further processing and transmits all information via a wireless interface to a base-station along the running track, where it can be analyzed by the coach and medical team. This allows the athlete to come as close as possible to his physical limits, in all safety.

Similar setups can be employed for improving medical diagnosis and health care, gaming, entertainment, communication, etc. They all show us that ambient intelligence is centered around four major properties:

- Embedded, ubiquitous, distributed *wearable computing*;
- Ubiquitous *wireless communication*;
- Pro-active *non-keyboard user interfaces*, putting the electronics in the background and people in the foreground;
- *Distributed transducer* systems with sensors and actuators for physical and chemical properties.

2 Properties of the Required Platforms

A Global System for Ambient Intelligence (GSIA, instead of GSM) will consist of one Wearable Digital Assistant per person and in the order of hundred smart sensors and actuators per person-aura.

M. Glesner, P. Zipf, and M. Renovell (Eds.): FPL 2002, LNCS 2438, pp. 790-794, 2002.

The WDA will execute all multimedia and game processing, determine global position (GPS), analyze biometric input, monitor health and control its environment. It will be able to see, hear and feel, as well as speak, show and stimulate. Using a radio interface with multiple antennas, it can communicate in a multi-mode manner with several wireless networks: long distance (kilometers) via GSM/GPRS/UMTS, medium distance (tens of meters) to wireless local area network (WLAN) base-stations and other WDAs with which it forms ad-hoc networks, short distance (one meter) to the smart sensors in its aura. Computing performance is estimated to be 10 to 100 billion operations per second at a power consumption below two Watt, i.e. a power efficiency of 10 to 50 MOPS/mW. The latter is necessary since they are battery operated and should last on a single battery charge for at least one day. Applications can be upgraded and new services downloaded to the WDA. Hence, they should be flexible.

The smart sensors and actuators combine the actual sensing or actuating device, the signal conditioning and digital processing and the wireless interface in one package, which often should be bio-compatible. They do not have to be flexible as they are expected to perform one function throughout its entire life. Most of them need to transmit or receive only a few hundred bits per second, in short bursts, and have very moderate compute requirements. However, their power consumption is limited to a hundred microwatt, since they do not possess a battery and should generate the necessary energy from their environment (e.g. motion, temperature, light, …). The required power efficiency is estimated at 100 MOPS/mW.

Power efficiency and flexibility are conflicting requirements (Figure 1). What can be seen is that power efficiency of traditional microprocessors today is two to three orders of magnitude less than for hardwired logic. On the contrary, microprocessors offer the highest degree of flexibility. The power efficiency needed for ambient intelligence can only be met today by hardwired logic; however, this does not provide the required flexibility. It can be seen on the graph that in a few years, when we are at the 65nm feature size, a mixture of hardwired logic, some re-configurable logic and a few processors for the less demanding tasks will make ambient intelligence feasible.

3 Case Study of a Smart Re-configurable Device

As a case study, we want to show what can be achieved today in building a smart re-configurable device. Assume you have 4 separate appliances: an MP3 audio player, an MPEG-2 video player, a PDA and a mobile phone. Each of these devices contains a few Instruction Set Processors (ISP) and several hardwired accelerators (marked as 'ASIC' in Figure 2).

What the consumer really wants to have is a single device that can run all listed applications at wish, even multiple at the same time. In that case, we add a re-configurable hardware section to the platform. Let us assume for example that the consumer wants to see a full motion full screen video on his/her appliance (Figure 3).

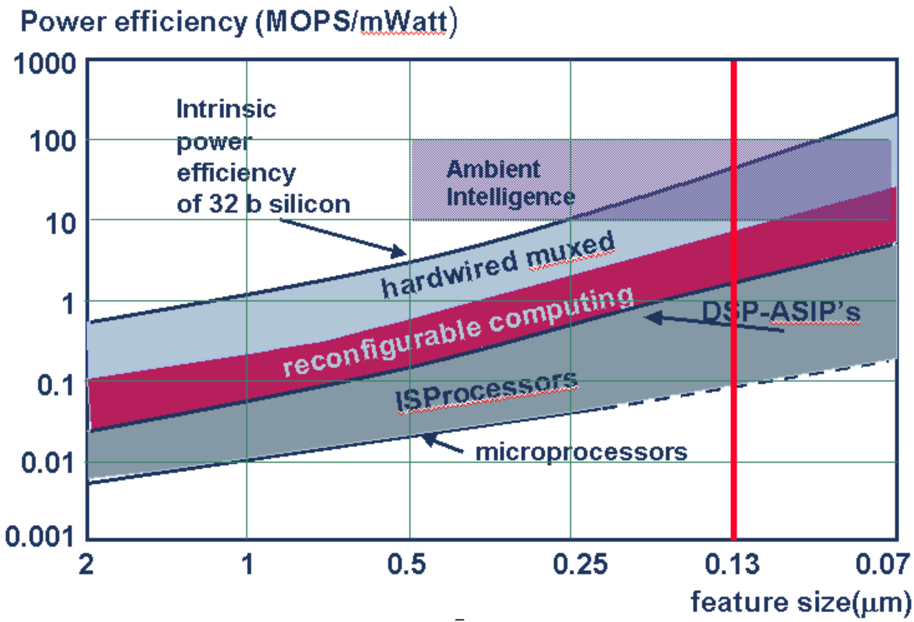

Fig. 1. Power efficiency versus feature size (Source: T.Claasen et al. (ISSCC99).

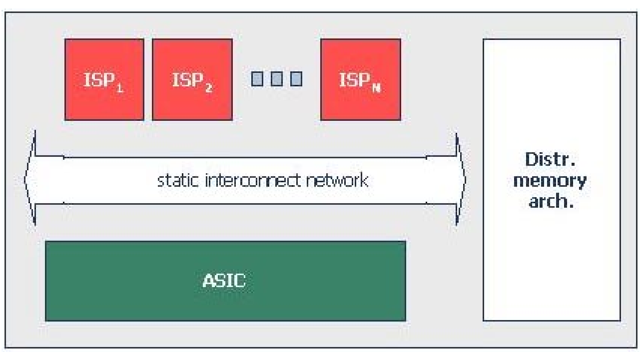

Fig. 2. Typical hardware structure of a traditional System-on-a-Chip (SoC) for a battery operated consumer electronics appliance.

Fig. 3. Multiple application appliance, running an MPEG-2 video decoder full screen.

For power reasons, we do not run the video decoder in software on an ISP, but we map it onto the re-configurable hardware (Figure 4).

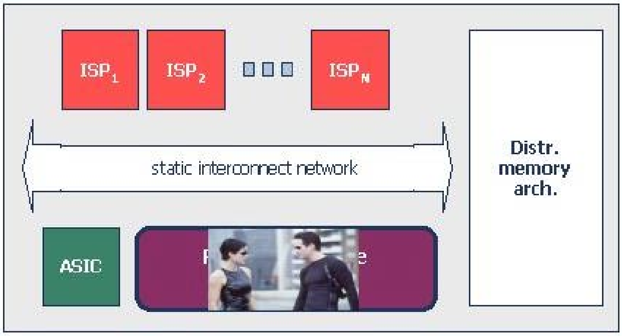

Fig. 4. For power reasons, the full motion full screen video decoder is mapped onto the re-configurable hardware.

When the consumer gets bored by the scene and wants to switch to a downloaded 3D game, while still seeing the movie as a picture-in-picture (Figure 5), the Real-Time Operating System (RTOS) moves the video decoder from hardware to software to free the re-configurable hardware resource for the computationally demanding 3D game; the reduced size video decoder fits on an ISP (Figure 6).

Fig. 5. The appliance now runs two concurrent applications: a full screen 3D game as well as a video decoder as picture-in-picture.

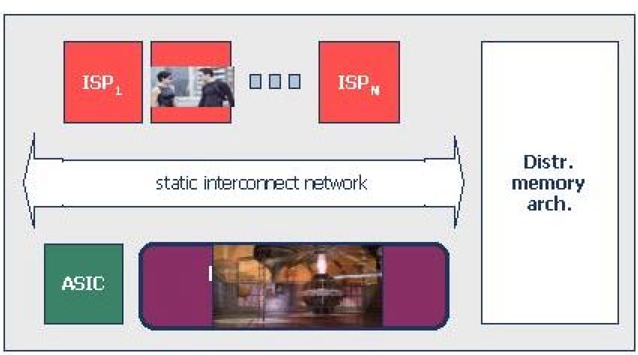

Fig. 6. The video decoder has been moved to software, to make the re-configurable hardware available for the demanding 3D game application.

To demonstrate the feasibility of this hardware-to-software migration under operating system support, without interrupting the running application and hence by automatically migrating the 18-bit wide words of the application status in the hardware to an equivalent 32-bit wide status in the software, we implemented this scenario on a Compaq iPaq, enhanced with a board containing a Xilinx Virtex II-6000 (Figure 7).

Fig. 7. Prototype platform demonstrating the migration of applications between hardware and software under operating system control.

4 Conclusion

Ambient intelligent appliances need a large compute power at very low energy. This can only be achieved by combining hardware accelerators, re-configurable logic and instruction set processors. Real-time operating system support must be provided to enable multi-threading in hardware as well as in software and to enable easy migrating of applications between hardware and software without interrupting the application.