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Assistive Human-Machine Interfaces for Smart Homes

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Computer systems have shown in the past (Zajicek, 2000) that they can be powerful allies in home-based health care and offer great potential to improve quality of life - but only if they are designed to take into consideration the specific needs of their beneficiaries. Satisfying usability as well as the functional requirements in such a home setting are equally critical. This paper discusses the development of user interfaces, following the "Designfor- all" philosophy, oriented towards a multi-agent system interacting with an intelligent engine. Originally, the system will focus on the control of white goods (large kitchen appliances) but will have scalability properties making it appropriate and extensible for the inclusion of other devices that may be deployed thereafter. The interfaces must be flexible enough to adapt to the targeted public, fit any user's preferences and/or needs and make the interaction as simple and intuitive as possible. This work is part of the EU FP6 IST e-inclusion 'EASY LINE+' project.

Keywords
User interfaces, Ambient intelligence, Design-for-all, Accessibility, Smart homes, Home

Disciplines
Computer and Systems Architecture | Digital Communications and Networking | Hardware Systems | Systems and Communications

Comments
This paper was presented at the Third Collaborative Research Symposium on Security, E-Learning, Internet and Networking (eds. U.G. Bleimann, P.S. Dowland & S.M. Furnell), (ISNRG) which was held in July 2007. It was published by the University of Plymouth and the symposium proceedings are available at http://www.cisnr.org This project is part of the easylineplus which is a European Project under the IST Priority in the European 6th Framework Programme for Research and Technological Development. Whose main objective is to develop prototypes near to market of advanced white goods in order to support elderly persons with or without disabilities to carry out a longer independent life which will compensate their loss of physical and/or cognitive abilities. The easyline website can be found here http://www.easylineplus.com/

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Abstract

Computer systems have shown in the past (Zajicek, 2000) that they can be powerful allies in home-based health care and offer great potential to improve quality of life - but only if they are designed to take into consideration the specific needs of their beneficiaries. Satisfying usability as well as the functional requirements in such a home setting are equally critical. This paper discusses the development of user interfaces, following the "Design-for-all" philosophy, oriented towards a multi-agent system interacting with an intelligent engine. Originally, the system will focus on the control of white goods (large kitchen appliances) but will have scalability properties making it appropriate and extensible for the inclusion of other devices that may be deployed thereafter. The interfaces must be flexible enough to adapt to the targeted public, fit any user's preferences and/or needs and make the interaction as simple and intuitive as possible. This work is part of the EU FP6 IST e-inclusion 'EASY LINE+' project.

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1. Introduction: Design aspects of smart homes for an ageing population

As a generic concept, *home automation* offers lifestyle improvement through the combining of various home systems into a unified, familiar, intuitive and non-threatening solution. Many of these systems are to be found in roles associated with the elderly and/or disabled and are about to become more significant than ever. With the baby-boomer generation about to enter retirement years soon, the demands made upon health services grow and, where possible, the need to reduce the need for human caregivers is vital. Due to the increase of healthcare facility costs, it is anticipated that more and more people will prefer to choose the *smart homes* solution for the range of benefits offered. Consequently, in the future, Smart Homes are expected to assist growing groups of senior citizens (Figure 1) where help is needed for independent living at home. Facilitating the control of household appliances (such as refrigerators, washing machines, dishwashers, cookers, etc. – the so-called *white goods*) and the home environment (lights, heaters, doors, windows, curtains etc.) through various devices that encompass multimodal and ambient interfaces is an obvious way to achieve this (England, 2005).

Outstanding Home Automation projects are already in evidence, often giving special attention to particular user interests or requirements. An example is *AutoHan* (Blackwell & Hague, 2001), developed to enable user-programmable specification of the interaction between appliances in a domestic house. Another is the *Metro Group*, using *Radio Frequency Identification* (*RFID*) technology in order to develop the "Future Store", where customers and staff experience the benefits of modern technologies for themselves.

The primary advantage of a *Home Automation System* (*HAS*) is in making it possible for the elderly and disabled to have a longer independent life - at home, rather than living in long-term care facilities. They are able to feel more secure, knowing that help will arrive quickly, if necessary, thanks to the security features that a HAS may include. Besides, the elderly are often unable to cook proper meals or are afraid of the risks they can face in the kitchen (falling, problems with hygiene, fire, burns, etc.). However, those domestic appliances are an essential part of their independent lives. Well-designed devices and/or adapted appliances to help the elderly will be a key in increasing their independence and thus reduce the need for institutionalisation.

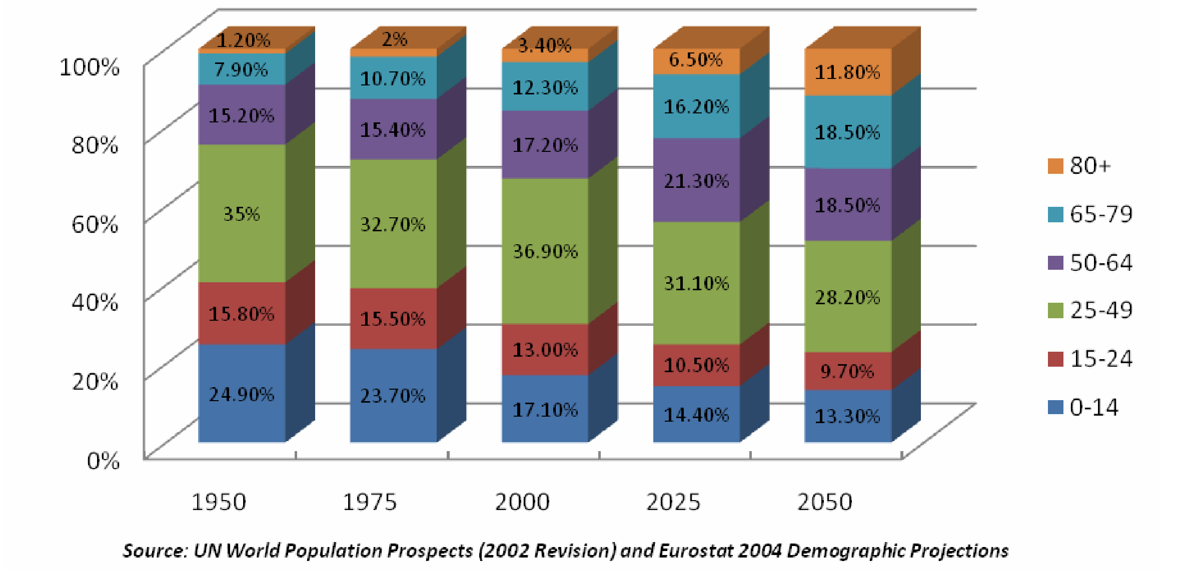

Figure 1. Population distribution in Europe per age group (1950-2050) (projected)

Through past experience, interface designers know that smart homes, suitable for the elderly and disabled, only truly fulfil their potential if accessibility barriers are identified in the early stages (Abascal et al., 2003). The design-for-all principle has to work for everybody and without any discrimination as a result of the *Disability Discrimination Act*, introduced in 1995. In many respects, designing smart homes for the elderly or the disabled is not so very different from designing them for people without any form of impairment. It is often better to consider the needs of this particular group as a subset of the general design-for-all principle within the overall design (Dewsbury et al., 2003).

2. Aims of the paper

We consider this research project as a step further towards the integration of computing technologies at home, in order to generate services at different levels. It addresses the concept of *Ambient Intelligence* (*AmI*), which, by combining computing and networking technologies, seeks to make the home environment more sensitive, secure and intelligent. To achieve this goal, several objectives have been established. The principal objective of this research is to develop *interfaces* for the white home appliances in order to support the elderly and/or disabled in carrying out tasks that might otherwise be difficult or impossible for them. The designed interfaces must be *secure* (as reliable as possible addressing the ethical and security issues linked to the health of individuals), *intelligent* (interfaces act adaptively depending on the user's situation or environment), be able to *cooperate* with the rest of the home equipment and be *scalable* for further extensibility.

This project, at this stage, is focused primarily on four types of device:

- Refrigerators
- Cooker hobs
- Dishwashers
- Washing machines

The intention is that, among the expected features of the four appliances, the interfaces designed will be able to help the user to control or monitor simply the following features:

- For the refrigerator: provide information on what items are inside, give a warning of expired products, identify incorrect temperature ranges (e.g. if the door has been left open or the thermostat requires adjustment, advise on products affected by interrupted cooling or incorrect settings

- For the cooker hob: warn of a switched-on hot-plate with no pot or pan on it, warn the user if a hot-plate has been left on warn of, and potentially deal with, excessive heat in inappropriate areas (e.g. excessive heat away from a hot-plate suggesting fire)

- For the dishwasher: recognise dishwasher-proof and non-dishwasher-proof dishes, validate levels of detergent added into the machine, automatically generate correct programme, duration and temperature

- For the washing machine: simplify the loading of washing machines, validate the correct amount of detergent and softener being added into the machine, identify and warn of inappropriate load combinations (e.g. whites and coloureds), automatically generate correct programme, duration and temperature

3. Modelling of a multi agent system in control of white goods

Since the 1990s, there has been accelerated development in *agent-based technologies*, due to their promise as a new paradigm for conceptualising, designing and implementing software systems (Sycara, 1998). These agent-based systems were autonomous or semi-autonomous, based in software and/or hardware, with the purpose of accomplishing tasks in dynamic environments. We generally define a *Multi-Agent System* (*MAS*) as a system composed of several individual agents, collectively capable of achieving tasks that would be difficult for systems having a single agent only.

In newer systems, this paradigm has already been refined with MAS's becoming more sophisticated, as shown in several recent publications (Mas, 2005, for example). Some agents are now capable of bidirectional interaction, either in the form of message passing or through producing changes in the MAS common environment. Agents can be autonomous entities, such as software agents or robots. A MAS can include human agents as well. Looking closer at the definition, it is easy to understand why the nature of the agents is sometimes a matter of some controversy. For example, a robot that cleans a swimming pool can be autonomous in the sense that is dependent only on a human operator to start it up (in fact, it could even start or stop by itself). Furthermore, an agent can even be a human being in view of the fact that they communicate and interact with the environment by means of making changes and executing actions in stigmergic collaboration.

A MAS usually has the following basic capabilities:

1. An awareness of environment changes
2. The ability to respond to events and requests
3. Communication between agents
4. Cooperation and coordination (Iwakura et al., 1997)
5. The ability to adapt to new environments
6. Efficiency in response and decision actions
7. A certain autonomy and fault tolerance
8. Overall multi-agent learning

An *optimised agent* should fulfil all the requirements mentioned above, although the approach to build those agents cannot be strictly defined by a MAS model since there are other factors to consider in the general design. The proposed MAS is focused on the creation of a software/hardware architecture to create accessible interfaces to control household appliances in the home, not as an independent system but as a part of a HAS. The first step in this process is to study the actual and future markets. It is important to observe the state-of-the-art before embarking upon a careful study about the user demands in order to identify the main requirements of the interfaces. These first steps are essential to identify accessibility issues, to design the user interfaces and, finally, for the success of the project in general. Also, the selection of technologies (see later sections) and the building of the software's architecture play important roles, particularly while defining the agents, because this involves many software components such as services, events, behaviour, states, properties and data (Mine 2001). Some will be implemented in the user interfaces - some not. As mentioned previously, a MAS requires to provide communication, cooperation and coordination efficiently between agents. An effective way to enhance the performance of all these communications is to establish a suitable content in each message depending on its nature or purpose and to ensure that the timings are correct in both *synchronous* (generally generated by automated processes) and *asynchronous* types of messages.

The proposed MAS classifies the different agents into *fixed* agents (generally agents that interact with the user through the displays and panels of each appliance), *portable* agents (agents that interact with the user using a portable interface within the smart home) and *external* agents (dealing with users outside the secured perimeter of a firewall, usually incoming services from the Internet). Each *Human Machine Interface* (*HMI*) must be clear enough to reduce the effort of any user to a minimum and will have to interact correctly with the rest of the agents to achieve an environment of ambient intelligence in the smart home.

Nowadays, more and more HAS's are being created, having different cooperating modules, some even including robots. A typical MAS for household appliances is shown in Figure 2.

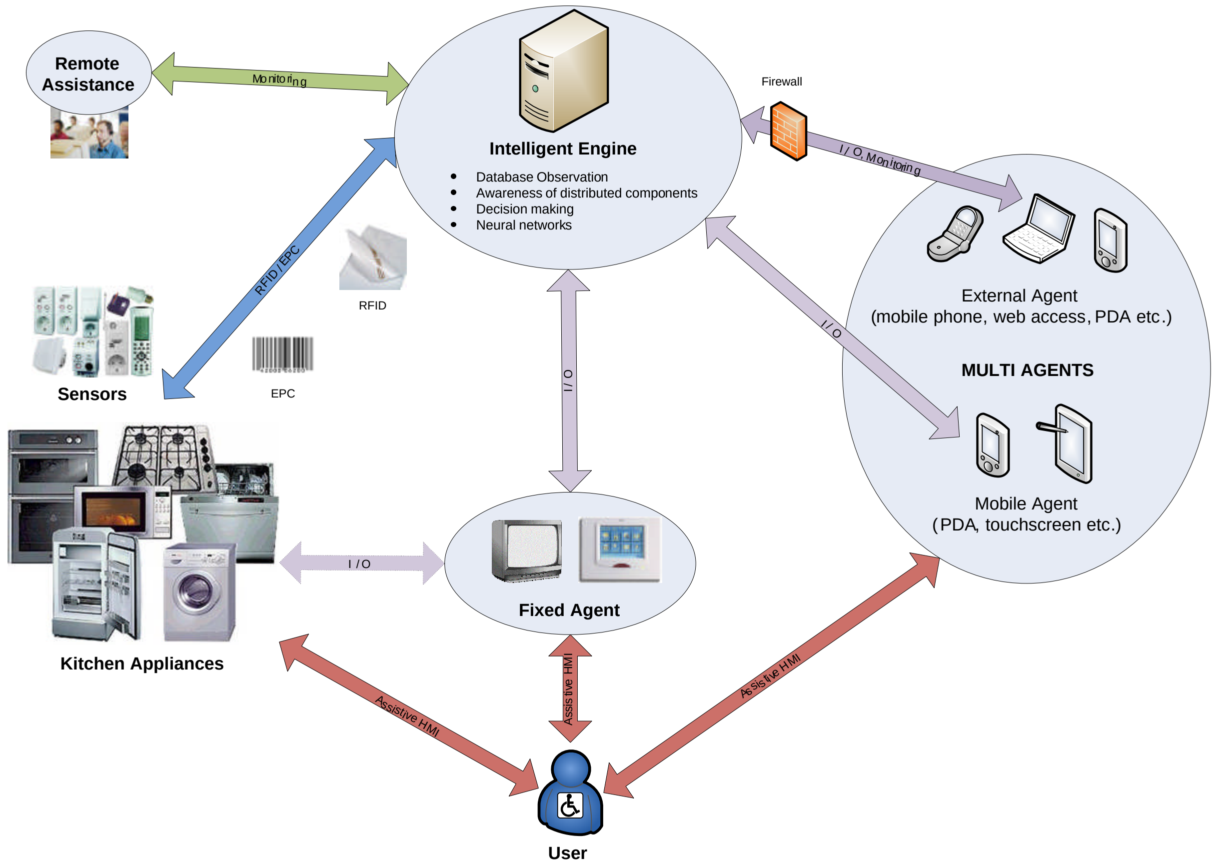

Figure 2. Multi agent system control flow

4. A framework to develop assistive interfaces for white goods

Building HMI's requires constant feedback from the users, the aim being to keep the general development of the project focused on delivering quality. This can be achieved most simply by adopting the aim of maximising the user's acceptance of the final product. One of the most suitable methodologies to develop the assistive interfaces for white goods is *Rapid Application Development* (*RAD*). RAD incorporates extensive user involvement, *Joint Application Design* (*JAD*) sessions, prototyping, integrated CASE tools (UML for example) and code generators. Using appropriate RAD tools will increase the frequency of prototyping and interaction with users. The following steps are included for each iteration of the development lifecycle:

1. **Surveys, analysis & design**. After enough data has been collected through surveys and interviews with potential users, interfaces must be pre-designed clarifying all possible system outputs and all possible user inputs, considering the objectives explained above.

2. **Planning and functional specification**. Establishment of functionalities that (genuinely) match user needs.

3. **Technology specification.** At this point the technologies to develop the application are selected.

4. **Development**. At this point, code is created.

5. **Prototype release, testing and evaluation**. There are essentially two ways to test and evaluate user interfaces: empirically by experiments with users and heuristically by simply considering interfaces and passing judgement according to the developer's own experience. A variation could be to assess the product against any available benchmarks. Usually, the favoured method will be the empirical one. Although analysing an interface heuristically can give an idea of the potential usability that it might have, the best way of assuring the usability of the interface is by experimenting with the user directly.

Although, all appropriate ethical issues will be considered throughout the development process, a complete treatment of the subject is beyond the scope of this paper. Also at end of the project, the form and function of all interfaces will be documented in full to determine the potential level of understanding a user may have without external or professional assistance. In this research, the interfaces produced will be tested in simulated real-life environments with real users.

5. Issues and limitations

Designing any HAS with the objectives and requirements described previously is a significant challenge. The fact that there are many recent investigations into HMI in various contexts (Holmquist et al., 2004, Shneiderman & Plaisant, 2005 and Muñoz et al., 2006, for example) demonstrate clearly that users must still have the last word and the chances of success in introducing home automation technologies into the market relies completely upon them. In addition to this, HMI developers for AmI systems may face the following particular issues or limitations:

- **Reduced scalability & reduced features**. This normally occurs when the development requires constant feedback from the users to increase the level of prototyping accuracy with the purpose of producing a good refinement of the final product. If used, time boxing can cause interfaces to have reduced features by their being pushed to later versions in order to finish a release in a short amount of time

- **Genuine interface accessibility**. It is a considerable challenge to make interfaces accessible for all, especially for people with cognitive, sensory and mobility impairments.

- **Privacy matters**. There is a balance to be struck between having greater privacy and having more computerised assistance in an AmI. Judging the preferences of a range of individuals, as well as accommodating individual needs will not be trivial

- **Cost**. Making the interfaces more sophisticated and giving them more features requires a bigger investment in new technologies. For example, for people with cognitive impairment (Muñoz, 2006) it may be possible to sense their behaviour and help them to make choices by using techniques such as motion/gesture tracking (Essa, 2001) but this will require advanced sensors, scanners and cameras, which will greatly increase the final cost of the HAS. Normally, biometrics have higher cost since they are still in their early development stages and they are not established in the market yet. The same is partially true of tangible interfaces (Holmquist et al., 2004 and Ullmer & Ishii, 2000) but here we are starting to see some affordable prices in the marketplace.

- **Accurate statistics**. The sampling requires acquiring sufficient resources and enough different user profiles to build up accurate statistics in order to gather reliable feedback to assure quality.

- **Cultural differences**. While supporting standards and making a design suitable for all, it is important to bear in mind the cultural differences, particularly expectations and restrictions, in different countries or regions.

As the different points above show, there are many issues and limitations to consider when creating a HAS, particularly when all its services are, in theory, oriented towards everyone at once! However, they clearly still have a great potential and it is only a matter of time for most difficulties will be overcome. The next section gives some examples of possible solutions.

6. Proposed solutions

People with special needs such as the elderly or disabled have particular characteristics or limitations caused either directly by ageing or any diseases which affect their daily activities at home (household tasks, mobility etc.) (Rodriguez-Acaso et al., 2003). Assistive technologies are intended to support people with such needs. However, to facilitate the design of a system for someone, we need to understand their capabilities and their limits first. Ageing implies a wide range of accessibility issues and all of them need to be considered as successful implementations of assistive technology are typically aimed at “designing for all” and not only for one disability (Swain, 2002 & Holic, 2004).

Any realistic design must cover most cognitive disabilities: sensory loss (vision, hearing), memory impairment etc. For that reason, the developed HMI’s must follow the *eight golden rules of interface design* by Ben Schneiderman (Schneiderman, and Plaisant, 2005). These are quoted as follows:

1. Strive for consistency in action sequences, layout, terminology, command use etc.
2. Enable frequent users to use shortcuts, such as abbreviations, special key sequence, regular actions, etc.
3. Offer informative feedback for every user action.
4. Design dialogs to yield closure so that the user is aware of when they have completed a task.
5. Offer error prevention and simple error handling.
6. Allow easy reversal of actions in order to relieve an essential part and encourage exploration.
7. Support internal locus of control so that the user is in control of the system.

8. Reduce short term memory load by keeping displays simple and consolidated multiple page display and providing time for learning the action sequences.

Furthermore, individuals who experience vision impairment will need an audible feedback from the system. As a result, the support of the interfaces must be made through a set of vocalisations for blind users that matches the text for limited vision users - and finally the standard GUI for sighted users (Gregor et al., 2002). With this solution of talking interfaces through built-in features, users can easily build a conceptual model of the system's interfaces. The individuals experiencing hearing impairment have less interaction issues as interfaces are essentially a visual display of information. An example of successful hearing impairment support will be when captions are displayed to increase accessibility for people with hearing disabilities. Finally, for persons with cognitive impairment, they should not have to retain an unreasonably large amount of information while interacting with a system. Messages as explicit as possible must be displayed in order not to confuse them.

7. Communications protocols

One of the major issues to be addressed in considering intelligent devices for help in extending independent living is the choice of communication protocol or protocols. Devices need to exchange information about their own states and about the user. There is plenty of choice. A large number of technologies have been developed over the last thirty years or so using different media to connect devices for various purposes within a home. Many of these could be used as existing or with adaptations; all have their strengths and weaknesses.

Common media employed include wireless, infrared and dedicated coaxial or twisted pair structured cabling. Some technologies use existing powerline (mains wiring) or telephone lines to carry data on top of the existing frequencies.

Established applications are diverse and include heating and ventilation control, lighting, security, baby alarms, intercoms and, more recently, audio, video and the Internet.

Dedicated cabling is expensive to install and infrared is limited to a single room so, for our purposes, the choice of medium really simplifies to either wireless or powerline. Unfortunately, both channels are now used by a bewildering array of competing and often conflicting technologies.

7.1. Powerline

X-10 is the oldest common home automation protocol. It was invented in Scotland by Pico Electronics in 1975 and is still widely used. It operates by sending a short burst (around one millisecond) of 120KHz carrier at a zero crossing to represent a 1-bit; the absence of such a burst represents a 0-bit. X-10 is simple and cheap but it only supports a raw data rate of around 50bps (at 50Hz) and is very prone to errors.

Universal Powerline Bus (*UPB*) has been developed by PCS Inc of Northridge, California since 1999 to address some of the weaknesses of X-10 (http://www.pcslighting.com). Capacitors are discharged to create 40V pulses in each half-cycle. Data is encoded by varying the exact position of each spike, a technique known as *Pulse Position Modulation* (*PPM*). UPB supports a raw speed four times greater than X-10 (200bps at 50Hz) and the developers claim far greater reliability.

The Homeplug Alliance (http://www.homeplug.org) has recently created their *Command and Control* initiative to provide a low cost, low bandwidth offering for the control market. They are to adopt a modem by Yitran, an Israeli company, as the basis of this but it is not yet on the market.

Yitran (http://www.itrancomm.com), formerly named ITRAN Communications Ltd., are currently offering a robust system of their own, which uses their patented spread spectrum *Differential Code Shift Keying* (*DCSK*) modulation. They provide the Physical and DataLink layers and Microsoft's *Simple Control Protocol* (*SCP*) sits on top. This offers data rates up to 7.5kbps.

7.2. Wireless

Wireless control systems within the home include the following …

Z-Wave routes messages through a network and can theoretically extend to great distances. It was designed by ZenSys, a Danish company which founded the Z-Wave Alliance (http://www.z-wavealliance.org). The Alliance consists of over 125 companies producing products based upon the ZenSys chips and it is well established in the market place. Z-Wave uses the unlicenced 868 MHz band in Europe and has a raw data rate of 40Kbps using *Binary Frequency Shift Keying* (*BFSK*).

Zigbee was developed by the ZigBee Alliance (http://www.zigbee.org). The specification was released in June 2005 and it is becoming a strong competitor to Z-Wave. It is based upon the open IEEE 802.15.4 standard at the PHY and MAC layers with upper layers developed by the alliance for specific application areas. ZigBee is a self-organising mesh network that supports a raw data rate of 250Kbps on the 2.4 GHz band or 20Kbps on 868MHz (in Europe). Zigbee devices are either *Full Function Devices* (*FFD*s) or *Reduced Function Devices* (*RFD*s). FFDs are typically mains powered and perform the routing and hub functions. RFDs are usually battery powered leaf nodes. The particular advantage of ZigBee over other technologies is that the RFDs have very low current drain in sleep mode but wake up very quickly when required. This gives them extended battery life of up to 2 years in some applications.

Both Z-Wave and ZigBee have heavyweight support in the industry and are competing head to head in the marketplace for supremacy. Z-Wave has the advantage of early market penetration in the home market whereas ZigBee seems likely to make rapid inroads into the commercial property market which is currently dominated by wired technologies such as BACnet.

Another strong competitor is *Insteon* (http://www.insteon.net). Insteon is developed by SmartLabs of California and is unusual in that it uses both wireless and powerline technologies simultaneously. Although not yet available in Europe, Insteon has made progress in the US where it is backwardly compatible with X-10. Insteon modulates a 131KHz carrier using BPSK over the powerline for a sustained bit rate of 2.88Kbps and and also offers an instantaneous bit rate of 38.4Kbps over the RF 904Mhz band.

The above are all lightweight protocols designed to be low-cost and provide very limited control. If it is simply a matter of collecting ambient information and user input and changing the state of devices, any of the above powerline or wireless devices would probably suffice – with the possible exception of X-10.

We need to consider whether future developments will involve increased data requirements and whether we should plan for this or whether simple control messages will always be adequate. We may wish to send voice commands to devices or have the view inside an appliance relayed to the television screen. The technologies already exist to do this, of course. There has been a lot of work carried out in recent years on delivering *Broadband data over Power Lines* (*BPL*). This operates either inside the buildings themselves or within 1.5Km to replace the local loop. The HomePlug Alliance (http://www.homeplug.org) uses sophisticated techniques developed by Intellon to deliver very high data rates reliably. HomePlug AV promises a raw data rate of 200Mbps – sufficient to support multiple HDTV streams. It spreads a signal from 4.5MHz to 21MHz over the power lines. There are other efforts around the world, particularly *OPERA* (http://www.ist-opera.org), an EU-sponsored project to provide powerline broadband access throughout rural and urban areas.

Very many homes are, of course, now using 802.11 WiFi to distribute data and media around the home and this is likely to increase as 802.11n products start to ship. These advanced systems are not without their problems, though. Chronic overcrowding in the unlicensed 2.4GHz band is becoming a significant problem and there are already reports of RF interference from wireless frequency signals being propagated along unshielded power lines (Stott and Salter, 2003).

Broadband components are currently too expensive to be considered for general control applications but things may change if distributed home broadband becomes ubiquitous. If 100Mbps services are already being piped around the home via powerline or wireless and the access devices have achieved economies of scale, there may be little point in also having some other lightweight protocol crawling alongside. Controlling white goods is not quite the same as controlling, say, lighting. There is not the same imperative to go for a very cheap ASIC to put into a £250 washing machine as there is to put into a £5 light switch.

For the moment, the best option for intelligent white goods is probably one of the lightweight powerline technologies to exchange control information and a wireless protocol to transfer user information between a mobile console and the controller. ZigBee seems to offer a reasonable data rate at 2.4GHz but there are still possible interference issues to be resolved.

8. Future directions and conclusion

The term "Universal design", also called "Design-for-all" in Europe, was coined in 1993 by Ron Mace, an architect who spent most of his life in a wheelchair and tried to contribute in a world not designed for people like him (Schwab, 2003). Design-for-all is intended to assist people of all ages and abilities in order to let them live as long as possible independently at home. The project's success is linked with the achievement of this idea and it is important to continue the research about the development of systems designed for all because there is still much to do in this field.

Presentation of data must be so simple that human interaction with the system will involve the minimum effort possible at the time of controlling the chosen appliances. It must be clear all the time what the different outputs mean and how the user will be capable of inputting data while interacting with the system with the minimum risk of error. To conclude, it is worth noting a few significant points. A contribution to the actual standards and low cost will be critical at the time of commercialising the final product and there may be considerations about taking the HMI design to the next level in the future, for example, applying advanced biometrics to interact more accurately with the users without raising noticeably the cost of the interfaces.

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