A Reality Check on Home Automation Technologies

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Abstract

Buildings account for more than 35% of the energy consumption in Europe and there is a political desire to lower the general energy consumption. Therefore a step towards more sustainable lifestyle could be to use home automation to optimize the energy consumption "automatically". One of the challenges to make this a reality is to make this kind of technology available at an affordable price and easy to get installed. In order for non-technical users to invest in this kind of technology it is important to guard against vendor lock-in. Thus, interoperability between devices from different companies will be essential. In this paper we report about some of the remaining challenges before this can become a reality. In addition we reflect upon the future trends that we foresee in this market.

Keywords: home automation, wireless, protocols, energy saving, interoperability.

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1 Introduction

Buildings account for more than 35% of the total energy consumption in Europe. While new buildings are more energy efficient and continue to improve, these enhancements are not enough to reach the European Union's (EU) ambitious goal to improve energy efficiency by 20% before 2020. More than 80% of the European buildings standing in 2020 are already built, so to reach EU's goal the existing buildings have to improve their energy efficiency too. Today, the energy consumption in private households is 22% of the total consumption in Denmark and the costs of private energy consumption have almost doubled since 1990 [28, 35]. Therefore it is relevant to reduce the energy consumption in private households and it has been so since the oil crisis in the 1970s. From the late 1980s on, the process has mainly been motivated by the negative consequences of fossil energy use for the environment, such as global warming.

Energy-saving strategies with focus on private households can be distinguished into the following categories [25]:

- *Technical improvements*, e.g. develop washing machines that use less energy to wash the clothes and develop energy saving light sources to replace incandescent light bulbs.
- *Different use of products*, e.g. wash the clothes at a lower temperature and remember to turn off the light when you leave a room.
- *Shift in consumption*. Indirect energy use can be reduced by consuming less energy-intensive products, by shifting expenditures to goods with a lower energy intensity.

The last two strategies require a behavioural change of the consumer and will often lead to decreased comfort or require an additional effort, but they require no initial investment of the consumer and will often save money. Therefore many studies have focused on social or psychological factors related to energy-saving behaviour while other studies focused on the effects of information and various types of feedback [25]. In general, technical solutions are more acceptable than behavioural changes with most consumers [25]. By use of home automation it is possible to combine the strategies. Home automation can be used as a technical solution to lower the use of the energy consuming products such as automatically turning off the light when no one is in a room, or turning off the heating system (e.g. radiators) or air condition when a window is open in a room. The energy reduction achievable by use of home automation is expected to be in the range of 5 to 10%. It will be possible to combine a home automation system with direct feed-back of energy consumption, and Darby [8] presents a review of savings demonstrated by a total of 38 feedback studies worldwide. She reports that almost all of the projects involving direct feedback produce savings of 5% or more.

In case we wish to lower the energy consumption at a global scale by use of home automation the technology has to be extremely widespread to have any measurable effect and this is not the case today. Although home automation systems have existed for many years they are still not in widespread use.

This paper starts off with elaborating upon the technical challenges with home automation in Section 2. Afterwards an overview of relevant communication protocols commonly used in connection with home automation systems is provided in Section 3. This is followed in Section 4 with a description of the project we have carried out trying to bridge the interoperability gaps between some of these protocols. In Section 5 we present the main result of this paper in the form of the lessons learned by trying to create interoperability in real living labs. This is followed by Section 6 which provides an overview of related work, while our expectation for future tendencies in the home automation area are presented in Section 7. Finally Section 8 provides some concluding remarks.

2 Challenges with Home Automation

There are already a lot of electronic devices in private homes with features which can help to manage and reduce energy consumption and improve comfort in the home. Unfortunately, it is not easy for non-technical people to establish a Home Automation (HA) network working in their own home in the way they would like it to. Today this kind of system is mainly used by technology freaks and wealthy people who can afford to pay a technician to install the system. The challenge really is to enable the people with few financial resources to purchase desirable sensors and actuators for a home automation system from different suppliers and potentially using different communication technologies and different protocols and then establish the interoperability and configure it to meet the desires of the residents (see Figure 1). This means that it is worthwhile to investigate whether it is possible to develop a system that is easy for non-technically minded people to install and configure. And later extend with new devices as the needs arise.

In order to investigate this opportunity a number of challenges must be addressed:

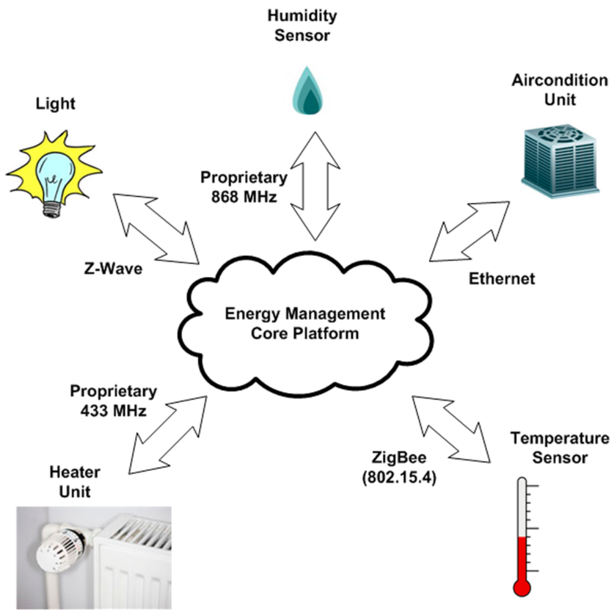

Figure 1 Examples of some of the many different physical link technologies of a classic home automation network to which a central unit must have interface.

- *Interoperability* is a key issue to success. Many different communication technologies are used between HA equipment, see Section 3 below. It is unfortunately unlikely that one network technology will out compete all others in the foreseeable future, and one integrated HA system is easier for the residents to manage and optimize for maximum energy efficiency.
- *Adding a new device* must be easy. HA systems will evolve over time and the residents will want to add new devices to their HA system or replace old malfunctioning devices. On a wired network this is often a simple task, but on wireless networks this is often a challenge. The problem on wireless networks is that there must be a certain procedure to ensure that the device joins the residents HA network and not a neighbours HA network. This procedure is called "pairing of devices", and this task must be easy for the user to accomplish.
- *Battery power* is an issue that influences the choice of wireless protocol used in a HA network. HA systems will often include a number of battery powered devices, e.g. temperature and PIR sensors. To achieve

a decent interval between change of batteries these devices cannot use the traditional Wireless LAN protocol 802.11, but use either a protocol based on 802.15.4 or one of the many proprietary low power network technologies (see Section 3 for more on this issue).

- *The User Interface* is another key issue. Many terms used in HA systems is unknown to most residents, so it is a big challenge to design a user-friendly interface that minimize the efforts necessary to configure a HA system. Some systems go for fully automated HA with no configuration required by the residents, others allow or require everything to be configured, thus demanding a lot of effort from the residents.
- *Cost* is a limiting factor for a widespread use of HA. The associated cost of installation and configuration can be prohibitive. The high cost of the majority of home automation devices is a limiting factor at the moment. Of course general experience from the consumer electronics industry shows that once the quantity of products go up, the prices will decline substantially.
- *Number of nodes* is an issue in larger buildings. Some protocols have a relatively small address space, and can only contain, e.g., 256 devices in a network. And even if the protocol standard defines a huge address space, then the manufacturer sometimes limits the usable address space in their implementation due to memory constrains in the devices.

3 Protocols Used in Home Automation

A typical HA system consists of a central controller that communicates with many distributed sensors and actuators. Most systems use either power line communication or wireless communication, but some systems can use both and some systems use other physical media, e.g. twisted pair cables. On either physical media many different communication protocols are used. In a short investigation we found more than 70 different standard or proprietary protocols were used by different HA systems. This is beyond the scope of this paper, so only a small collection of the protocols used are presented here.

3.1 Power Line Communication Protocols

Power line communication technologies use the household electrical power wiring as a transmission medium, and this enable HA without installation of additional control wiring. Power line communications systems operate by impressing a modulated carrier signal on the wiring system. Since the power wiring system was originally intended for transmission of AC power, the power wire circuits have only a limited ability to carry higher frequencies. The propagation problem and electrical noise are some of the limiting factors for power line communication.

Typically HA power line communication devices operate by modulating in a carrier wave of between 20 and 200 kHz. Each receiver in the system has an address and can be individually commanded by the signals transmitted over the main supply. These devices may be either plugged into regular power outlets, or permanently wired in place.

X10 is an international and open industry standard for communication among electronic devices used for home automation [36]. It primarily uses power line wiring for signalling, where the signals involve brief radio frequency bursts representing digital information, but a wireless radio based protocol is also defined. The protocol was developed in 1975 by Pico Electronics in Scotland, and was the first general purpose home automation network technology and is still used today. Data rates are around 20 bit/s, thus only simple commands like turning devices on and off can be transmitted and it takes approximately 0.75 seconds to transmit a command. Only 256 devices can be addressed in a network.

CEBus (EIA-600) were published in 1992 by Electronic Industries Alliance (EIA) as an enhancement to X10 [7]. CEBus is a set of specification documents which define protocols for products to communicate over power line wire, low voltage twisted pair wire, coax, infrared, wireless, and fiber optics. It uses spread spectrum modulation on the power line. The transmission rate is variable, but the average rate is about 7,500 bits per second. CEBus transmission packets vary in length, depending upon how much data is included. The minimum packet size is 64 bits, which at an average rate will take about 0.009 second to transmit. The standard defines 4 billion device addresses that are set in hardware at the factory.

P1901 is an IEEE standard for broadband communications over power line networks defining medium access control and physical layer specifications and was published December 2010 [16] . The P1901 standard includes two different physical layers (PHY): The OFDM PHY is derived from the HomePlug AV technology and is deployed worldwide in HomePlug-based products. The Wavelet PHY is more narrowly deployed, primarily in Japan.

G.hn is the common name for a home network standard (G.9960/9961) being developed under the International Telecommunication Union (ITU-T) and promoted by the HomeGrid Forum [19]. It supports networking over power lines, phone lines and coaxial cables with data rates up to 1 Gbit/s, but can only address up to 250 nodes in a network [24]. Recommendation G.9960 specifies the Physical Layer and the architecture of G.hn. Recommendation G.9961 specifies the Data Link Layer. G.hn's main focus is broadband communication not home automation but devices in a home automation system may use this protocol.

3.2 Wireless Communication Protocols

The requirements from a HA system to a wireless communication technology is low-cost, low-power, range from 15 to 100 meters and only low transmission rates are needed. These requirements are close to those associated with Wireless Personal Area Networks (WPANs), the main difference is that for a HA network a wider range is preferable. The IEEE has developed a standard to meet these requirements. This standard is IEEE 802.15.4 which was first published in 2003, but is now superseded by IEEE 802.15.4-2006. The later version resolves ambiguities, reduce unnecessary complexity and increasing flexibility in security key usage. The 802.15.4 standard only specifies the physical layer and media access control layer. For the upper layers there are several different opportunities like ZigBee, 6loWPAN or proprietary protocols.

Supported network topologies is a an important issue for a WPAN, as routing can extend the range of the network and minimize the number and extend of radio dead spots that might occur in a home. The three most relevant topologies are star, mesh and tree as shown in Figure 2 and described below:

- *Star*: each device is connected to a central controller with a point-to-point connection. All traffic that traverses the network passes through the central controller. The main advantage of the topology is that it is easy to implement and the primary disadvantage is the lack of routing, which limits the network range to twice the point to point range of the radio front end used.
- *Tree*: a central "root" controller (e.g. the ZigBee Coordinator) is the top level of the tree, and is connected to one or more other devices that are one level lower in the tree (i.e., the second level). Devices on the second level with routing capabilities may have connections to devices on a lower level (i.e., the third level) – and so forth as shown in Figure 2.

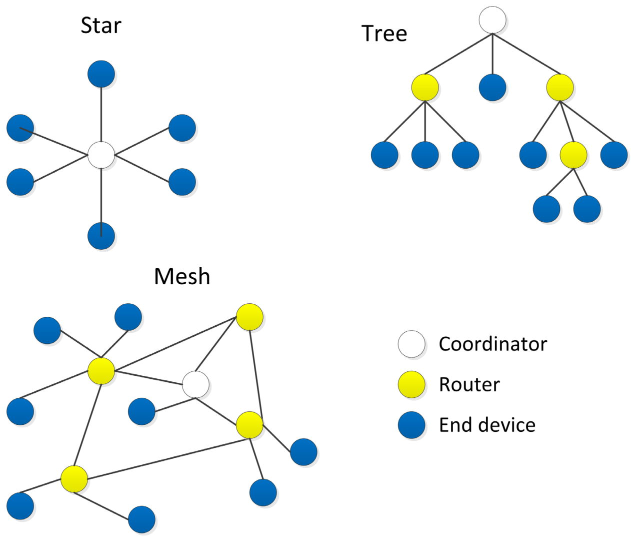

Figure 2 Network topologies.

- *Mesh*: each device must also serve as a router for its neighbour devices. In a network that is based upon a partially connected mesh topology, all of the data that is send between devices in the network takes the shortest path (ideally) between devices. This requires that the devices must perform some type of logical routing algorithm to determine the correct path to use. Well-designed mesh routing algorithms have self-healing capabilities, which make mesh networks very robust.

ZigBee

ZigBee is a low-cost, low-power, wireless networking proprietary standard. The ZigBee Alliance is a group of companies that maintain and publish the ZigBee standard. The term ZigBee is a registered trademark of this group, not a single technical standard. The low cost allows the technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the protocol supports mesh networking which provides high reliability and larger range. The ZigBee specification is based on the IEEE 802.15.4-2003 standard for wireless personal area networks [4]. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption –

individual devices must have a battery life of at least two years to pass ZigBee certification.

The ZigBee stack includes a Stack Profile which can be used to specify the market the protocol will be used in to make better interoperability [31]: e.g. the Home Automation profile is a standard for products enabling smart homes that can control lighting, environment, energy management and security. The Smart Energy profile is a standard for interoperable products that monitor, control, inform and automate the delivery and use of energy and water.

The important device types which makes up the ZigBee network is listed below and in Figure 2 it can be seen how they can be placed in a network of different topologies:

ZigBee coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network since it is the device that started the network originally. It is able to store information about the network, including acting as the Trust Centre and repository for security keys.

ZigBee Router (ZR): As well as running an application function, a router can act as an intermediate router, passing on data from other devices.

ZigBee End Device (ZED): Contains just enough functionality to talk to the parent node (either the coordinator or a router); it cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life. A ZED requires the least amount of memory, and therefore can be less expensive to manufacture than a ZR or ZC.

6loWPAN

6loWPAN is an acronym of IPv6 over Low power Wireless Personal Area Networks and it is the name of a working group in IETF [22]. The base specification developed by the work group is RFC 4944 that specifies how IPv6 packets can be sent over IEEE 802.15.4 based networks. The idea of 6LoWPAN is to offer an IPv6-based solution for critical embedded wireless requirement of high reliability and adaptability, long lifetime on limited energy and within highly constrained processing resources to minimize cost. 6loWPAN uses the same RF-chips and low-level protocols as ZigBee, so it have similar specification except the overhead of using IP which reduces throughput. 6loWPAN is an open standard.

Z-Wave

Z-Wave is a proprietary technology developed by the private company Zensys which is the only supplier of the chips implementing the physical layer. The standard is supported by the Z-Wave Alliance which is a consortium of independent manufacturers who have agreed to build wireless home control products based on the Z-Wave standard [3, 17, 37]. The radio mainly operates in the 900 MHz ISM bands (868 MHz in Europe, 908 MHz in the United States) which often is an advantage, because the 2.4 GHz RF band is typically subject to significant interference due to 802.11 and 802.15.1 devices. The first generations of Z-Wave chips allow transmission at 9.6 and 40 kb/s data, but the recent Z-Wave 400 series supports the 2.4 GHz band and offers bit rates up to 200 kb/s. The transceivers from Zensys allow up to 30 meters indoor range (100 meters outdoors), and the protocol supports the Mesh network topology which enables a wider range, however the address space allows only a maximum of 232 devices in a network. In practice only main powered devices are cable of routing, so a network of only battery powered devices will be unable to route packets.

ONE-NET

ONE-NET is an open-source standard for wireless networking [34]. It is designed for low-cost, low-power control networks for applications such as home automation and sensor networks. It is not tied to any proprietary hardware or software, and can be implemented with a variety of low-cost radio transceivers from a number of different manufacturers. ONE-NET uses UHF ISM radio transceivers and currently operates in the 868 and 915 MHz frequencies but the standard allows for implementation on other frequencies. ONE-NET features a dynamic data rate protocol with a base data rate of 38.4 kbit/s. Indoor range is up to 100 meters (over 500 meters outdoors). Use of mesh mode network topology can extend operational range.

A more detailed description of some of the wireless protocols used in HA networks can be found in [17].

4 The Minimum Configuration – Home Automation Project

In 2008 the Danish Enterprise and Construction Authority decided to fund the project “Minimum Configuration – Home Automation” (MC-HA) with a budget slightly below 1 million Euros. The objective of this project is to develop, through user-driven innovation, a unifying concept of how different electronic solutions can be configured in the home, in such a way that they will become applicable and relevant for users [5]. The partners in the MC-HA project are:

Aarhus School of Engineering	http://ase.iha.dk
The Alexandra Institute	http://www.alexandra.dk
Seluxit A/S	http://www.seluxit.com
Develco Products A/S	http://www.develco.dk

The project is based on participatory design of a multidisciplinary cooperation incorporating user involvement and innovation [30]. Participatory design is a new approach for a number of the involved industrial partners and during the process they learn to use the new methods, while describing the applicability of them for industry value. The project have worked with the following two groups of users:

1. A reference user group consisting of families with or without children
2. Two families who will live in conventional houses in Denmark and Portugal (as living labs).

Based on the user driven innovation, a home automation framework has been created, called the Extendible Protocol Independent unit Controller (EPIC) [35]. Once matured, this framework will be open source for anyone to use. During the development of the initial version of the EPIC framework the following focus points have been given the highest priority:

- *Protocol Interoperability*: The framework must be able to handle several communication protocols in a way that is transparent to the user. This should cover both wireless and power line communication approaches.
- *Solid Backbone*: Since it is the idea that several third party developers will make additions to the framework in the future, it is essential that the framework core is stable. This will ensure that the entire system will not crash due to a faulty addition of new components.
- *Testing Platform*: The user driven innovation created a lot of feedback on how the home automation system shall work. It is important that the framework enables rapid prototype testing of several user interfaces, to support the frequent user feedback. The challenge for the updates of the Graphical User Interface (GUI) comes when the concepts underlying the core components change during the development.

The EPIC platform has been developed and a number of electronic devices (sensors and actuators) have been purchased as commercial products to be integrated in the minimum configuration – home automation setup. Unfortunately (as could have been anticipated) progress on the user interface has not come as far as we had expected because of a large number of interoperability challenges that have turned up with the communication with the different devices. The challenges with different versions of different wireless protocols are described further in Section 5 below.

5 Results Derived from the MC-HA Project

When the MC-HA project started there were no commercial ZigBee devices for home automation on the marked in Europe, but we got hold of a prototype. So the goal for our system was to achieve interoperability between this device and some of the commercial Z-Wave devices for home automation.

We expected the main problems to be concerned with interoperability between the different protocols, but we discovered soon that it was difficult just to setup a functioning net based on only one protocol. In our living labs we made use of both ZigBee and Z-wave devices and we experienced different kinds of challenges with these. The main issues are presented in the subsections below.

5.1 Z-Wave Issues

Regarding the Z-Wave based devices we have encountered the following issues:

- *Network setup*: One of the largest problems for an end user is to setup the network. To do so the user is expected to press a button on the network controller's hardware or software user interface and then press a button on the device that should join the network. The problem is that if the device is already on a network, then it will not join a new network, and simply ignores the press on the button. As a consequence an end user will get no response of what is happening and is likely to assume the device is defect. A new Z-Wave enabled device is not expected to belong to a network when the end user purchases it in a store, but this has been the case with most of the commercial devices we have purchased for the project. From a technical perspective the problem is easy to solve. You remove the device from (any) network. To do so, you just have to select remove device (or something similar) in the network controller's software, and then press a button on the device. The problem is that you need a network sniffer or knowledge about the protocol to figure out what the problem is, and how to solve it.

- *Interoperability*: Interoperability between devices, all using Z-wave, from different manufactures is not as we expected. Devices using the Z-Wave protocol are expected to communicate with each other regardless of who originally manufacturers the devices. However this has unfortunately not been the case in our project. The devices will typical communicate to some extend, but they are rarely fully compatible, and some devices behave strangely when added to a network controller from a different company. One example is a device that would only route packets in one direction, and another device that destroyed the network when added to a network controlled by a controller from a different company.
- *Reachability*: We experienced practical problems with the reachability of the wireless devices in the test houses. Z-Wave devices are supposed to have a range of approximately 100 feet (or 30 meters) in "open air" conditions, but with reduced range indoors depending on building materials. Our experience from the two test houses are that the indoors range is much less. An example is a battery powered sensor placed in the kitchen (device A in Figure 3) that was unable to reach the controller approximately 8 meters away with no concrete walls in between. When we added a switch plug-in (device B in Figure 3) to the network, this device was able to route between device A and the coordinator, so we were able to setup a network that covered every room in the house from one coordinator. But we were surprised that routing was needed for such a short distance.

5.2 ZigBee Issues

Regarding the ZigBee based devices we have encountered the following issue: The first ZigBee specification was ratified in 2004 and made public in 2005, so we expected the ZigBee protocol stack to be mature and stable. However, in our project we found that the protocol stack implementation was not stable yet. This may not be the case for all vendors, but the ZigBee devices used in the project were prototypes from a project partner and this gave us significant additional work because they had to update their firmware frequently. These updates would almost always require changes in our code as

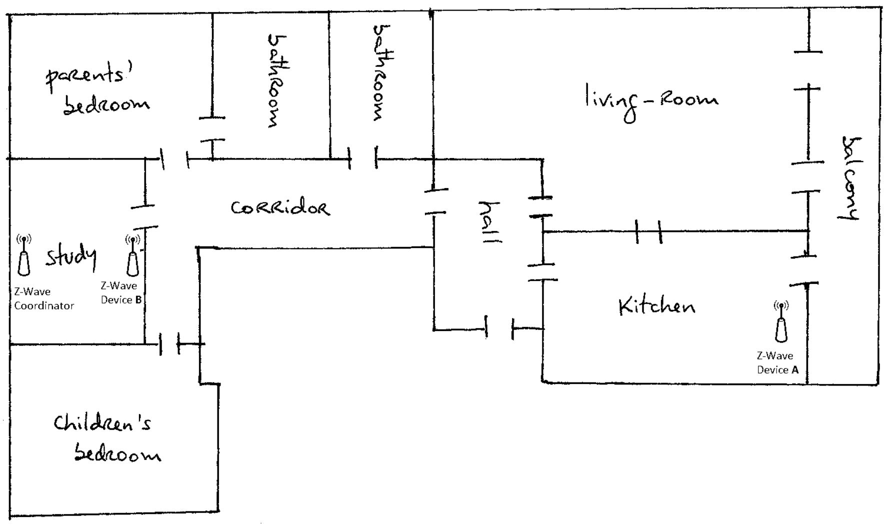

Figure 3 Layout of the Portuguese house (a living lab).

well. One of the major changes was the shift from the ZigBee 2006 protocol stack to the ZigBee 2007 stack release profile 2 (called ZigBee Pro).

5.3 Power Line Communication Issues

Power line communication (a proprietary protocol) was added to our project after we finished the development of our generic communication framework. This was a good test for difficulties in adding support for a new protocol to the framework. It turned out to be rather easy. It only took two weeks to integrate power line communication in our framework, and the power line devices worked very reliably in the test house.

6 Related Work

Currently a number of large European research projects target the use of embedded systems for energy efficient buildings. These range from a project with a cost of more than 17 million Euros such as eDIANA (Embedded Systems for Energy Efficient Buildings) [6], to IntUBE (Intelligent Use of Buildings' Energy Information) [26] and AIM (A novel architecture for modelling, virtualizing and managing the energy consumption of household appliances) [1, 32]. Apart from these projects with their primary focus on embedded systems for energy efficient buildings, there are numerous other projects within the area of development of energy efficient buildings where use of embedded system are only one part of the solution. An example of such a project is "Home for Life" [18]. In addition a number of international research projects across Europe have attempted to solve the problem of interoperability between different link layer technologies by designing a middleware software component making the specific link layer technology transparent for the user. The two largest of these are the Amigo (Ambient Intelligence for the Networked Home Environment) project [14] and the Hydra (Middleware for Networked Devices) project [13].

6.1 eDIANA

The project's main goal is to improve energy efficiency in residential and non-residential buildings through the use of embedded devices. The project is focused on the conceptualization, design, development, demonstration and validation of new devices operating in a uniform platform called eDIANA. The eDIANA Platform is a reference model-based architecture, implemented through an open middleware including specifications, design methods, tools, standards, and procedures for platform validation and verification. The eDIANA Platform will enable the interoperability of heterogeneous devices at the Cell and MacroCell levels, and it will provide the hook to connect the building as a node in the producer/consumer electrical grid. The partners publish many reports at the eDIANA website [11] and links to scientific publications from the project can also be found there. The project has chosen HomePlug 1.0 Power Line Communication technology to be used for providing connectivity between the Cell Device Concentrators (living/working units) and the MacroCell Device Concentrator (buildings). For communication within the Cell the IEEE 802.15.4/ ZigBee protocol stack with Home Automation or Smart Energy profiles will be used.

6.2 IntUBE

The project's main goal is to develop tools for measuring and analysing building energy profiles based on user comfort needs. The intend is then to integrate these into Intelligent Building Management Systems to enable real-time monitoring and optimization of energy use. Neighbourhood Management Systems will also be developed to support efficient energy distribution across groups of buildings. These will support timely and optimal energy transfers from building to building based on user needs and requirements. Regarding communication standards IntUBE recommends the use of OPC UA (LonWorks, Konnex), BACnet and oBIX.

6.3 AIM

AIM's main objective is to foster a harmonized technology for profiling and managing the energy consumption of appliances at home. The project will develop a generalized method for managing the power consumption of devices that are either powered on or in stand-by state, and will introduce energy monitoring and management mechanisms in the home network. AIM will also provide services for power distribution network operators (e.g. metering service for energy planning) and for network operators (e.g. remote monitoring and management).

6.4 Home for Life

The goal is to build a sustainable, affordable house that uses readily available technology to negate its imprint on the environment and to promote the health and comfort of its residents [18]. VKR Holding, a private company based in Denmark, is financing a project that will build eight experimental houses in five European countries.

6.5 Amigo

The Amigo (Ambient Intelligence for the Networked Home Environment) project [14] focuses on interoperable middleware aiming at enabling ambient intelligence within the networked home environment by addressing the seamless integration of networked devices and related application services within the home system. The scope is not limited to classic home automation devices, but also aims towards consumer electronics as well as mobile and PC platforms. The Amigo architecture is specifically designed to realize an open networked home system that dynamically integrates heterogeneous devices as they join the network. The dream is to have a home filled with electronics devices that can all "talk to each other" in the future.

Some of the other issues and challenges to the project has attempted to solve is that it is complicated to configure the many different networks within the home automation network. The complexity is high and it is not possible to put too much complexity in the edge-devices due to resource constraints (a strong focus on cost minimization). The architecture has therefore from the beginning been designed and implemented with a service oriented focus. It means that one should no longer think about the washing machine as a device by itself, rather a service provider of a certain functionality (in this case the ability to wash clothes). In this way the network consists of a number of functionalities that work together. By doing this, Amigo facilitates it that the functionalities can interoperate directly. Additionally the Amigo middleware ensures that existing communication protocols can still be used along with new types of communication links. One example is the classic X-10 that Amigo can convert and make a part of the next network.

6.6 Hydra

The Hydra project [13] has from the start aimed at designing, implementing and validating middleware for networked embedded systems that allows developers to develop cost-effective, high-performance ambient intelligence applications for heterogeneous physical devices. The underlying communication layer is considered transparent. It is a tool for further development, targeted towards developers and product manufacturers. The architecture is service oriented like was the case with Amigo. Again Hydra is not targeted specifically towards home automation. Its general structure is equally relevant for other application domains like healthcare, agriculture, etc. Hydra additionally deals with the challenge of developing a framework for secure and trustworthy communication, while at the same time supporting self-adaptive interplay of different components, not only sensors but also controlling components and actuators.

6.7 EnTiMid

The EnTiMid project [23] takes the middleware approach even further. However here the initial setup is based on the idea that one unique and universal middleware is a dream. Therefore to solve this issue, a new generation of schizophrenic middleware in which service access can be generated from an abstract service description has been build. The implementation is called EnTiMid. It is a schizophrenic middleware which supports various services access models (several personalities): SOAP (Simple Object Access Protocol), UPnP and DPWS (Device Profile for Web Services). The model personalities are generated using a model driven engineering approach.

7 Future Tendencies

The consumer is interested in interoperability, ease of use, configuration and installation and the overall cost of a HA system. The current solutions that combine multiple areas of HA such as an alarm system and a heating control system, may be easy enough to use, but these systems still require a relatively highly skilled person for the installation and the configuration. Furthermore in many systems the home owner will not be able to adjust the system to her or his requirements without consulting an expensive expert. A good solution to the usability problem would thus also solve the cost problem up to a point. In the past companies such as Apple, Nokia and Microsoft have made complex technology more accessible to the wider public. The same leap in usability is needed for the widespread acceptance of home automation solutions. As there is currently increasing activity in the development of such solutions it is only a matter of time until the right solution emerges.

In other domains there have been a strong movement towards global standards. It would be very difficult to get a decent market share for a wireless interface card for labtop computers which was incompatible with the WiFi specification, or a hand free head set for a cell phone incompatible with Bluetooth. But even standards within the field of home automation exist, there is no clear movement towards them. A study by IMS Research, "The World Market for Low-power Wireless 2011 Edition" [27] finds that, in 2009, of the 20 million IEEE 802.15.4 ICs shipped, fewer than half were ZigBee certified. And within home automation 802.15.4 is only one of the many different protocols used. One of the reasons why this is the case is due to the number of standards. There are too many competing standards and no obvious winner among them. Another reason may be the structure of the market. In the home automation marketplace there are many small national companies compared to the cell phone marketplace which is dominated by large multinational companies.

Currently there is no clear winning standard among the proprietary and open standards available. In the past the winning standards in other areas had a good open specification. These standards include TCP/IP, USB, HTML and XML. An open standard without the requirement of certification and the payment of royalties to some part of the industry can form the basis for a competitive an successful market introduction of home automation.

A winning home automation solution will probably comprise multiple standards both wired and wireless. Furthermore such a solution will probably include use of proven technology such as 802.11 or bluetooth as this will

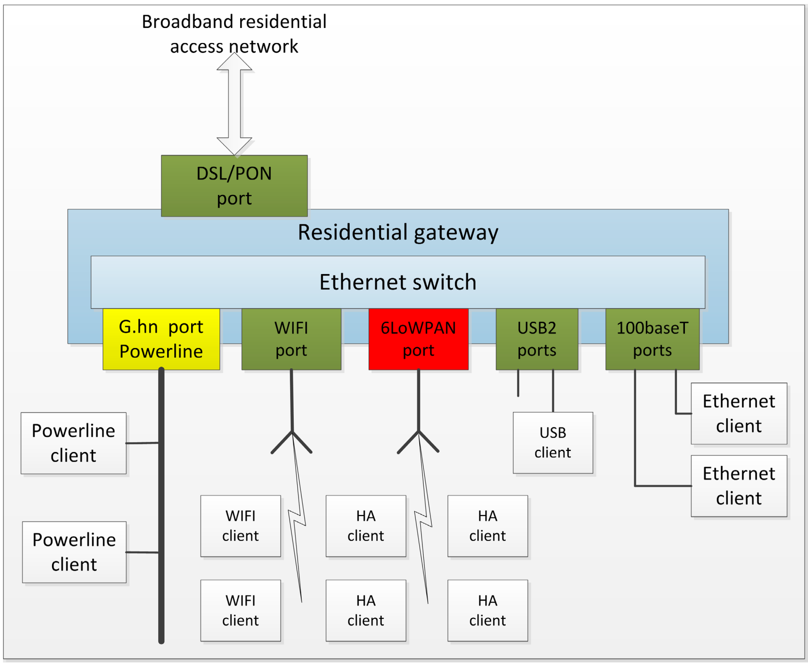

Figure 4 Vision for a HN topology that suits Home Automation.

make the integration into the existing infrastructure easier. The interoperability can be achieved by using proven technologies such as IPv4 or IPv6 based protocols. Oksman and Galli [24] has a vision of one integrated infrastructure for the home. They promote G.hn and figure 2 in their paper [24] shows an example of Home Network (HN) topology associated with residential access. But they miss one important issue to fully connect everything. Many home automation systems include several battery powered devices such as temperature sensors. They need a wireless low-power protocol. To integrate smoothly into the other protocols used this could be 6LowPAN over 802.15.4 as shown in Figure 4. Then IP could be the protocol to integrate the different network technologies.

Depending on the specific area where the solution is used, be it automatic meter reading or an alarm system, different solutions will probably become the de facto standards. Therefore middleware solutions that can seamlessly bridge between multiple standards are the only option for the foreseeable future as long as there is no clear winning standard in the home automation market. On power line there are two competing standards: G.hn and IEEE's

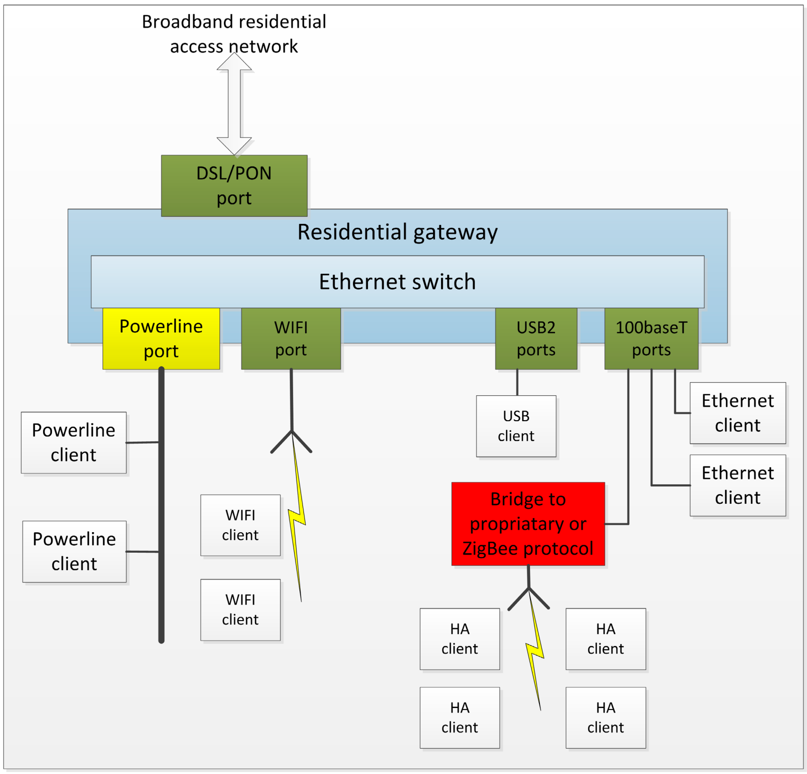

Figure 5 A more realistic vision for a HN topology that include Home Automation.

P1901 and only time can tell if one of them will win the market and leave the other and all the proprietary protocols behind. On the wireless media there are many alternatives to the ZigBee standard. Even if ZigBee has better performance than most of the competing protocols (e.g. bandwidth and range), this does not necessarily make it a winner. In the beginning of 2011 there are still relatively few (25) ZigBee certified products for home automation [2]. Therefore a more realistic HN topology is the one shown in Figure 5.

Furthermore a good open application layer protocol for home automation is needed. Such a protocol might be based on XML or the more suitable EXI standard defined by the W3C [33].

8 Concluding Remarks

Despite the promising potential for using intelligent home automation and improving the energy consumption in private homes [29], it seems that the maturity of the electronic devices to be used in such networks are not yet where they need to be for this to really have any measurable effect. To achieve a measurable carbon emission reduction from home automation technologies the technology has to be extremely widespread. It must be employed in a significant part of the private households, i.e. it must be extremely easily employable. It is amazing how difficult a simple task such as adding a new device to a wireless network can be for an end user to accomplish. In our view it is disappointing that it is so difficult to realize a heterogeneous network of home automation devices that can interoperate appropriately. We believe that in order to remedy this situation both the industry for wireless home automation electronics as well as the standards institutions for wireless technologies quickly needs to create sufficient standards, preferably with backward compatible interoperating protocols. For the power line some of this is being done by ITU through the G.hn standard, promoted through the HomeGrid Forum [15].

One way of overcoming some of the challenges we have found in the MC-HA project is to move wireless home automation (actually both wireless and fixed network parts) into a pure embedded Internet setup [21]. This was initially proposed already in 2001 by Finch [12], but it was rejected since it was considered a far to heavy-weight type of solution. However, major advances in sensor networks as well as small scale sensor electronics have changed this situation significantly. With technologies such as the IETF 6LoWPAN [22], it is now feasible to run an IPv6 solution even on an 8-bit micro controller [10,20]. On top of that, the "upper" layers like the web server are being adapted to very resource constrained platforms [9]. With such an approach IPv6 will offer one single network layer that can cover all aspects. Additionally, different link layer technologies can be used in the same home network at the same time, wireless as well as fixed.

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Peter Gorm Larsen is currently a professor at Aarhus School of Engineering where he act as the team lead for the software engineering team. After receiving his M.Sc. degree at the Technical University of Denmark in Electronic Engineering and Computer Science in 1988, he went to industry to bridge the gap between academia and industry. He later returned and did an industrial Ph.D. degree which was completed in 1995. He gave industrial courses all over the world, and had an industrial career until he decided to return to academia in 2005. His prime research interest is to improve the development of complex missing critical applications with well-founded technologies. He is the author of more than 70 papers published in journals, books and conference proceedings and a couple of books.

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