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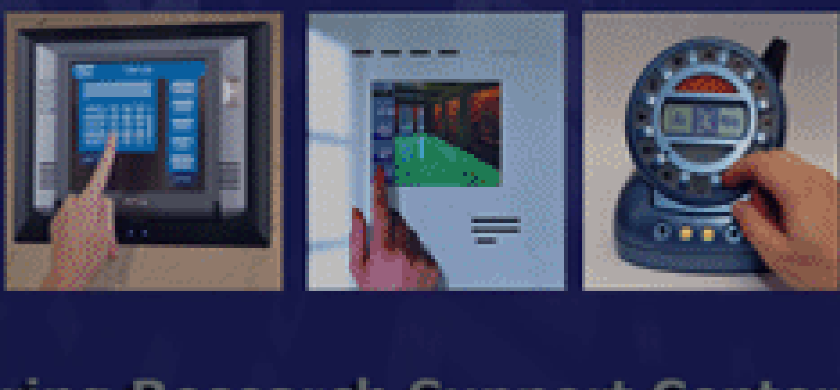

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# Smart home interoperability: the DomoEsi project approach*

J. M. Maestre and E. F. Camacho

*Departament of Systems and Automation Engineering*
*Escuela Superior de Ingenieros, Seville*
*pepemaestre@cartuja.us.es, eduardo@cartuja.us.es*

**Abstract**

*The home automation market is characterized by the great number of systems available to the end user. The recent bubble in the building industry made the situation even worse due to the birth of new proprietary systems. The success of the digital home concept depends on the ease of integration between home automation systems and other consumer electronic equipment pre-existing in the home. In this paper the interoperability issue is addressed and the approach followed in the project DomoEsi is presented.*

***Keywords:*** *Interoperability, UPnP.*

## 1. Introduction

The paradigm of the digital home offers the users the dream of an intelligent environment that learns and adapts to their preferences and needs. In the practice, however, there are numerous constraints that move the dream far away from reality: the high cost of many systems, capacity problems, lack of standardization, etc. From all of them, the most worrying one is the absence of real interoperability between real systems. There is no unified procedure to address the problem far away from some initiatives such as OSGI (Open Systems Gateway Initiative) [1], UPnP (Universal Plug & Play) [2] o Jini [3]. Without the success of any of these proposals, the pieces of the digital home puzzle won't be ever put together satisfactorily for the end user.

The international home automation market has changed little in its brief history. In the last 30 years there has only been a surviving technology: X-10 [4]. Apart from this de facto standard, there are other systems that have enjoyed the necessary success to establish themselves as solid options in their market segments. KNX [5] and LonWorks [6] are the best examples in this way, both of them supported by international standards. In the context of proprietary systems as Delta Dore [7] or more recently Z-Wave [8] can be stood out. The particular case of the Spanish market deserves a special remark. The bubble in the building industry in the last years of the 90's and the first of this decade was the perfect culture medium for the development of many new systems. After the explosion of the bubble few systems survived. Ingenium [9] and IPdomo [10] are good representatives of this generation.

In all emerging markets the compatibility between systems plays a crucial role for the success of the market itself and for the development of the involved technologies. The market is still guided by the offer and not by the demand and this is just a proof that at the moment

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there is no ideal choice among all the available ones. The best choice to satisfy the needs of any user comes from the mix of different systems and technologies in the same installation [11-14]. There is a real need for mechanisms to connect the different home automation technologies.

In this paper it is shown the way this integration problem is addressed in the project DomoEsi. DomoEsi is carried out at the Escuela Superior de Ingenieros de Sevilla, in the Automaion and Engineering department. Many works have been done under the standard UPnP to show the benefits of interoperability and to develop a flexible and low cost home automation system.

The paper is organized as follows: first, the interoperability problem and the most relevant initiatives are reviewed, specially UPnP. Next the project DomoEsi is detailed through a brief description of all its present components.

## 2. Interoperability

The concept of interoperability can be defined as the transparent compatible connection between equipment from different manufacturers. The most traditional sense of this concept is extended here. It is very interesting the integration not only between different home automation systems but between a given system and consumer electronics equipment present in most homes. Precisely this is the ultimate goal of several standards as OSGi, Jini or UPnP.

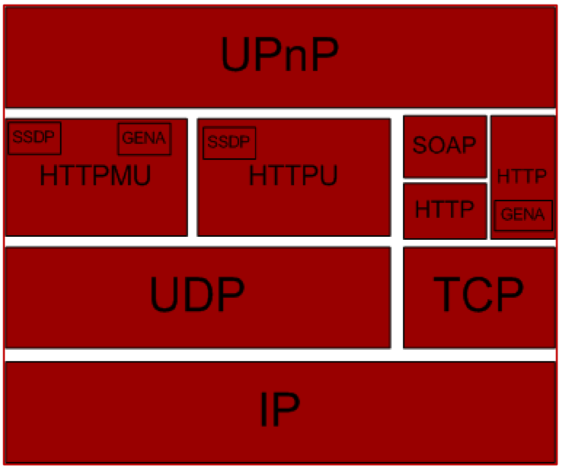


Figure 1. UPnP Stack.

UPnP is an architecture for the interconnection or any kind of electronic device. Its goal is to explain de plug & play concept to devices connected in a network environment. The architecture is open and based on the stack of TCP/IP protocols, that eases the control and data transference between devices in the home network. UPnP is promoted by the UPnP Forum, a group of companies that develop and spread the standard. This association was constituted in 1999 and accounts for more than 700 members.

In [2] it can be found a detailed explanation of the working of UPnP. For the reader who is not familiar with this protocol a simple explanation of the protocol will be provided. Two concepts related with different functionalities are needed to understand UPnP: device and control point functionality. A UPnP device is an object that embeds services and variables to the rest of the network. In order to clarify these two concepts imagine an UPnP printer. A service the printer could offer the rest of the network would be *printing*. The variables are related to the state of the UPnP device. In the case of the printer a possible variable could be *printing_state*, whose value is 1 if the printer is printing an 0 in other case. Other UPnP devices can subscribe to the value of this variable, so that whenever the printer changes the value of the variable *printing_state* it notifies this event to all the interested devices. In order to subscribe to a certain variable or to invoke the remote services offered by the devices control point functionality is needed. This functionality is embedded in those devices interested in doing something else than offering services to the network, that is, those interested in controlling other devices. Without loss of generality a device is said to be a control point if its only purpose is to control other devices and do not offer services to the rest of the network.

The multimedia environment defined by UPnP is a little bit different. Three concepts are needed to understand the way it works: render, server and controller functionality. A media render is a device capable of reproduce the contents from a remote source. A media server is a source device capable of providing contents to a remote destination. A media controller is a device capable of triggering the reproduction of a given content by a media renderer from a media server.

Notice that all these definitions are not related with the implementation. All these profiles just define behavior rules for networking and do not have anything to do with the device itself. In fact an UPnP device can be either software (in this case we talk of a virtual UPnP device) or hardware. From the network point of view all these concepts are entities that offer and request some kind of service.

The main feature of the UPnP architecture is that no configuration is required from the user so that any connected device is detected and configured automatically with an IP, a logic name and informed of the services that the network offer. In exchange the device offers its capabilities to the rest of the network. All this procedure is based on existing protocols and formats (figure 1), something that eases the introduction of UPnP in any informatics equipment.

Unfortunately UPnP does not enjoy the desired commercial success, and the same can be told about the rest of similar initiatives. Besides, the lack of authentication between the devices is potentially troublesome and therefore a revision of the standard is required. Another issue to have into account is that the two working versions of UPnP, 1.0 and 1.1, are based in some protocols that were not definitive in the moment the versions were released. The only facet where UPnP has truly succeeded is in the field of multimedia applications such as audio or video streaming, and other new standards as DLNA (Digital Living Network Alliance) [15] employ UPnP for this. A second version of the standard is being prepared and retrocompability with the versions 1.1 and 1.0 is foreseeable. Besides there are other developments very close in the concept as DPWS (Device Profiles for Web Services) [16].

Nowadays, without any succeeding standard in this difficult field, it is precise to impulse home automation solutions able to join in the same installation a great number of heterogeneous systems. Instead of waiting until a standard is consolidated it is preferable to begin bringing the benefits of interoperability to the end users and show this way the real potential of the smart home for its inhabitants' life.

## 3. DomoESI

DomoEsi is an own project elaborated in the department of Automation and Systems Engineering of the University of Seville. The objective of the project is the creation of a flexible low-cost home automation system. The project is being developed in different stages by students in their master thesis.

The system is based in the standard UPnP. Although this standard is eminently distributed, the heart of the interoperability is in a PC that works as centralized control element and provides all the necessary hardware for control point software and the bridges that interact with the other technologies present in the home automation installation.

Up to date many different systems have been integrated in the project DomoEsi. They will be enumerated and the functionalities they provide to the system analyzed.

### 3.1. IPDomo

This home automation system, twice awarded by Domogar, which is the biggest Spanish fair in domotics, as the best home automation system, is the first of this list due to its trivial compatibility because it works under the UPnP protocol.

The family of products of IPDomo includes an UPnP control point, a multifunction card to control lights, blinds and plugs, an alarm card and, finally, a card for a entry videophone. All these cards are prepared to work with a wired Ethernet network.

Due to its native UPnP capabilities IPDomo allows trivial integration of audio/video multimedia events, that can be easily controlled from the control point. This feature makes this system stands out in comparison with the traditional systems, much more focused to basic control and automatism functions.

As the whole project works under UPnP, all the functionalities provided by IPDomo are used in the DomoEsi project. The DomoEsi system can be controlled from the IPDomo control point and the IPDomo cards can be used from the DomoEsi control point. As the IPDomo control point offers several interesting features such as the definition of variables for advanced macro programming or a web server with an interface to control all the devices in the system, it has been used widely in installations with DomoEsi elements. To ease the access to the system to any type of user a flexible Flash interface has been programmed. This program connects with the IPDomo control point's web server and allows the separation between the application and presentation layer, something that IPDomo's software itself do not allow.

As it was said previously, the control point itself imposes the only constraint in an installation. It is the only mandatory element that has to be present. Any common PC is enough to run the control point. For example, IPDomo provides a 800Mhz Pentium III to execute the control point. Besides this PC may provide additional functionalities, being the most remarkable the possibility of deviating the calls received from the entry videophone to a mobile phone via Skype. Another interesting possibility is the installation of UPnP media server and renderer (a renderer is a software that plays the content provided by the UPnP server) in the same PC, so that the same PC is the multimedia and home automation engine.

At this point it is necessary to evaluate the economical impact that IPdomo's elements have on an installation. This system can be classified as a medium cost system. The average price of the different cards is around 400 euros. The control point software is provided by 100 euros.

### 3.2. X-10

A X-10 network controls and monitors devices at home but in a very basic form. There can be up to 256 devices in the network governed with a reduced set of 16 orders as turn on or off, dim or bright, etc. Although the short length of its control frames (around 20 bits are needed to complete an action), its low data transmission rate (50bps in Europe and 60bps in America) produce an appreciable delay between an order and its execution. Likewise, given the noisy character of the electric wires and the filtering effect introduced by some devices as the transformers in the power sources the reliability of the system is low, specially if precautions are not taken at the moment of preparing the installation. The counterpart to the limited X10 features is its cheap price, something that explains the great penetration of the system 30 years alter its creation. This makes X-10 and optimal candidate for low cost home automation installations. It is remarkable as well that X-10 is a de facto standard and since 1997, the year that the patent expired, the standard became open.

The X-10 network is accessible from the power line. There are several commercial transceivers that allow the access from a PC to the power line. In this project the Marmitek CM-11 has been used, although the software could be easily adapted to other devices due to the similarities between the models. The bridge has been developed in a software level. This way the X10-10 network is shown as a virtual UPnP device that can be governed from a UPnP control point. The software bridge also offers events that the control point can subscribe to, so that the UPnP network can detect changes in the X-10 network. This allows, for instance, the use of X-10 alarms in the installation.

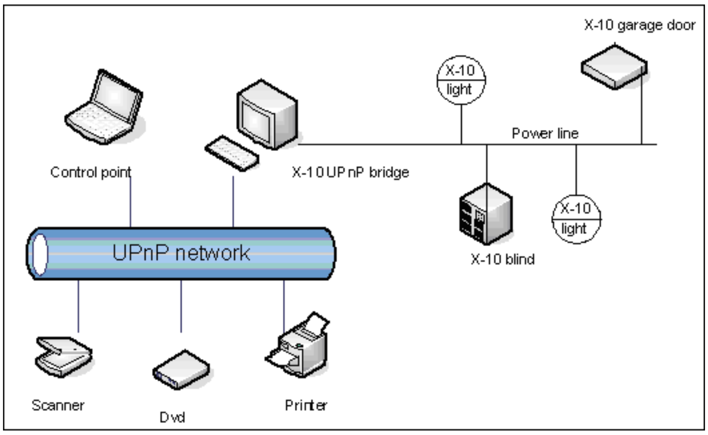


Figure 2. X10-UPnP integration.

The implementation of this integration allows future enhancements of the X10 home automation installation because the X10 installation is shown as a single UPnP device with independence of the number or X10 devices connected.

Summing up, the services offered by the software bridge are:

a) Transparent link between the two networks, X-10 and UPnP, so that any UPnP control point is able to detect both UPnP and X10 devices.

b) Order transmission service from UPnP to X-10: the software bridge takes as parameters the house code and the device code of the order. An additional field for X-10 devices that need extra information is included.

c) X-10 event notification: when the state of a device inside the X-10 network is modified (for example when a user employs an RF remote controller to turn a lamp on by means of an RF-X10 converter) the bridge notifies it to the UPnP devices that are subscribed to its events.

d) Stand alone mode: the software bridge can work alone without the need of a UPnP network to control the X-10 devices from a computer. Macros can be programmed as well so that by itself it is a X-10 control device.

The economical impact on an installation of X-10 devices is very low. A typical X-10 element may cost 30-40 euros and there is a huge variety of devices and manufacturers. In order to use X-10 elements it is mandatory to get a CM11 module, whose price is around 50 euros.

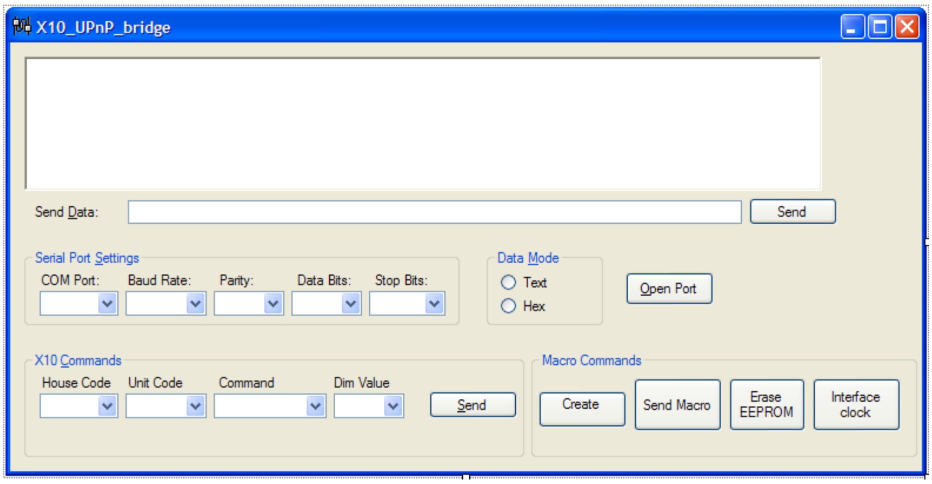


Figure 3. X10-UPnP Software bridge screenshot.

### 3.3. Wiimote

The famous controller of the Nintendo Wii videogame system [17] can be integrated as a home automation controlling interface via Bluetooth. This device stands out for its versatility and can be easily adapted to installations for people with special needs. The user can govern its home through the controller in three different ways: pressing its buttons, moving the controller (the accelerometers inside the controller detect the motion in axes x, y and z as it can be seen in figure 4) or pointing it to some direction (an infrared camera inside the controller is used to calculate the position with the aid of two infrared beacons).


Figure 4. Wiimote motion axes.

From all the ways to use the controller the one with more applications is the motion recognition through the accelerometers. In the next figure it is represented the evolution with the time of the signals corresponding to the *z* and *y* accelerometers for a given motion. With the adequate processing it is possible to recognize any kind of complex pattern as was proved in [18].

The services the Wiimote-UPnP software bridge offers the rest of the system are based in the generation of UPnP events everytime an action is performed with the controller. The Wiimote offers the user the possibility of controlling the home in an easy and intuitive way. The current version of the software lets the user change the device under control pressing the buttons. Once a device is chosen it can be controlled with motions. For instance, if the controller is inclined up or down while a blind is controlled it will raiser or lower. An inclination to left or right will dim the light when the user is controlling it. Finally, the buttons plus and minus can be used to change the reference temperature for the A/C system when it is controlled or the volume or channel on the TV when it is under control. It can be seen that the UPnP events the bridge generate can be programmed to trigger a great variety of actions. It depends on the programmer then how to associated effects and causes in the system.

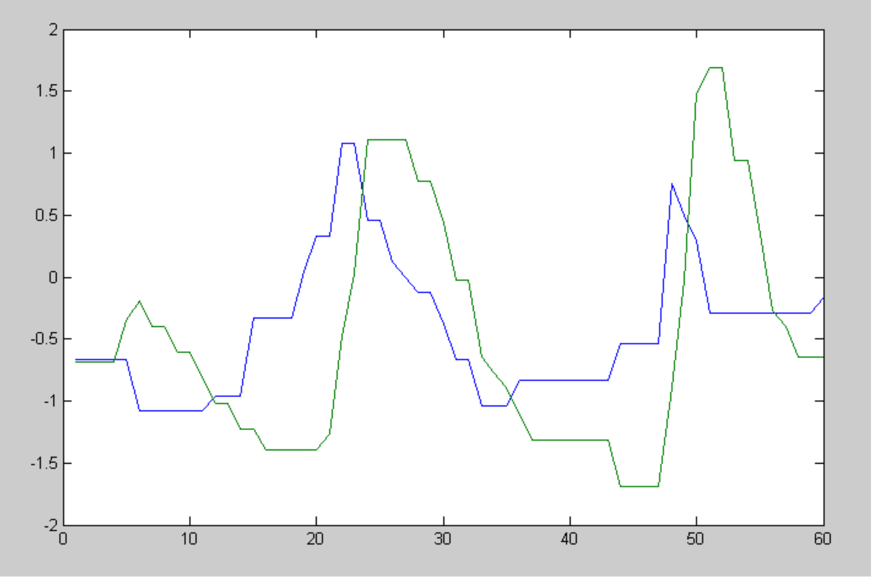


Figure 5. Signals for axes z e y with respect time (s).

The software developed also permits the use of other peripherical from the Wii family as the Nukchuk or the Wii Balance Board. This increases the control possibilities but normally requires the software to be adapted to the concrete user needs, mainly due to that this way of controlling the system is very well suited for handicapped people, whose problems usually require ad hoc installations. Anyway the standard version of the UPnP software bridge is general enough to cover most user needs by programming the control point rather than the bridge software itself.

Again, the economical impact of the Wiimote controller in an installation is low. The price of the controller is about 40 euros and the Bluetooth adapter needed for the PC does not exceed 20 euros.

### 3.4. Infrared

In spite of its age, this technology is still the most employed to govern the consumer electronics devices as home as the TV, HiFi or A/C. From a practical point of view there are many devices in a home that can be controlled via infrared. The same happens with most home automation technologies in the market: they have an infrared interface to trigger events in the system. Thus an adequate control of infrared is one of the keys for a real integration of home automation system and devices in the digital home.

A software bridge to build an UPnP interface to control the GC-100 was programmed. This device is designed to govern infrared equipment.

Figure 6. GC-100 Models [19].

As it can be seen in the figure 6, the GC-100 is designed to work in an Ethernet network. The device is connected this way to the UPnP control point. The control point can send orders to the GC-100 that it will repeat via infrared. Besides the control point can receive infrared commands as well through the GC-IRL, an expansion add-on that is connected to the GC-100.

The emitting services the infrared software bridge offers include the memorization of a list of infrared commands that can be repeated any moment. This lets the home automation system to turn on and off devices, change the channel or volume of TV and HiFi equipment, the change of parameters for A/C devices, etc.

The reception services the infrared software bridge offers include the identification of infrared commands received through the GC-IRL. This can be use as a triggering event to execute macros in the system. For instance, with a standard remote controller the user could control the whole system.

The GC-100 family price is variable depending on the model chosen. The smallest one is around 200 euros and the biggest is around 400 euros. However, if the price is too high for the user, his IR needs can be indirectly covered by the X-10 IR emitting and receiving devices that are available in the market. These devices provide worse performance, but their cost is again over 40 euros.

### 3.5. Zigbee

ZigBee [20] is a standard based on the IEEE 802.15.4, a specification for the physical (PHY) and medium access control (MAC) layers in the personal area networks protocol. The Zigbee alliance, the group of firms that support the standard, has added the specification for the network (NWK) and application (APL) layers on top of the othe two to complete the ZigBee stack for this kind of networks. This stack is represented in figure 7 and it specifies the necessary rules to establish the communication between Zigbee devices.

Zigbee has been designed to support a great variety of applications that require low cost and low power devices, with a more sophisticated connectivity than the previous systems.

This standard is focused to a market segment uncovered before, with low wireless data transmission and low connectivity cycle. The reason to promote a new protocol is to allow the interoperability between the devices manufactured by different companies. Home and building automation, hospital, industries and any kind of facility that needs a control network will take advantage of this technology.

Nevertheless this technology is still far from the mass market. While the standard is finished and the first commercial devices appear a development kit has been integrated in the DomoEsi project to show the benefits of Zigbee. The goal of this integration is the localization of an user inside the home [21].

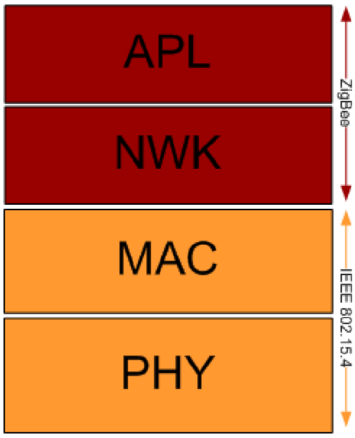


Figure 7. ZigBee Stack.

In figure 8 it is represented the Zigbee home positioning system. There are Zigbee beacons with a known position inside the home. These beacons allow the calculation of the unknown position of a Zigbee device at home by means of the signal strength. The calculations are performed according to a Weighted centroid localization algorithm [22][23][24]:

$$P(x,y) = \frac{\sum_{j=1}^{n}\left(w_j B_j(x,y)\right)}{\sum_{j=1}^{n} w_j}$$

where $w_j$ is a function of the distance from the beacon to the mobile Zigbee card and the receiver characteristics and $B_j$ is a two dimensional array with the position of the beacon $j$. In our experiments the following value was chosen for $w_j$ .

$$w_j = \frac{1}{\left(d_j\right)^g}$$

In this formula $d_j$ stands from the distance from the beacon to the Zigbee card and $g$ is constant that has to be tuned in order to weight the influence of each distance in the calculation of the centroid. Notice that closer beacons have greater influence in the calculations.

In figure 9 it can be seen the ideal case for the calculation of the centroid. Even in this case all the parameters have to be very well tuned in order to obtain a precise result for the position of the user. In a real environment, the situation is much worse because walls and furniture introduce great disturbances in the signal strength. To cope with this difficulty the UPnP Zigbee bridge offers to the system an approximation of the real position of the user. Notice that it is not so important to know the real user position inside a certain room; but it is key to know the room where the user is. So, what the bridge provides is an estimation of the room where the user is. This task is much easier to compute with a great precision and allows the system to react to the changes of room of a user. This way, for instance, an user carrying a Zigbee card can be followed by the home automation system. Thanks to UPnP the programmed application informs the control point about the localization of the user and the control point acts consequently. So the system reacts according to the position of the user, for instance turning lights or other equipment on or off.

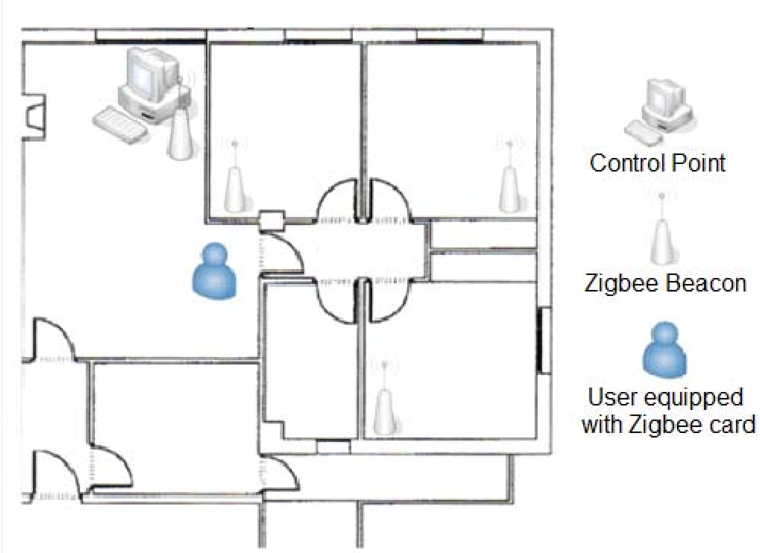


Figure 8. Zigbee home positioning system.

The economical impact of the Zigbee devices in an installation is relatively low. Each card is around 50 euros. It is necessary to stand out that in case that this functionalities are included in the installation a minimum of two cards have to be bought. The reason for this is that one of them works as a Zigbee modem for the PC apart from its beacon functionality.

### 3.6. Voice and speech technologies

DomoEsi has also an UPnP interface that offers the possibility of providing spoken messages to the user. It also recognizes spoken commands from the user. The functionalities this software provide are:

a) Voice recognition: with the aid of the libraries of the Microsoft's Windows Speech Recognition included in Windows Vista UPnP events can be generated from spoken commands made by the user.

b) Text to Speech: with the aid of a voice synthesizer spoken messages are given to the user to communicate him events, alarms or news.

These services do not have economical impact for the installation when the PC operating system is Windows Vista or Windows XP. If it is not the case it is not possible to use this application.

$$w_j = \frac{1}{(d_j)^g}$$

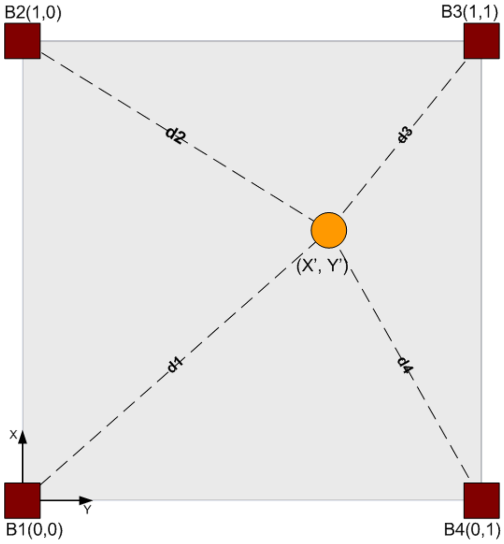


Figure 9. Weighted centroid localization algorithm.

## 4. Conclusions

DomoEsi is a project with the purpose of providing the user a low cost and highly integrable system. However it is difficult to provide a good estimation of the price of a complete installation. Due to its versatility it depends on the concrete user needs the elements that will be present on the installation.

The only basic component needed for the system to work is a PC, preferably with windows XP or Vista so that all the applications can be used, where the UPnP control point and the different software bridges run. To provide an estimation of the cost of an installation, it is possible to get a basic system at home by 600 euros. This would include a PC with all the software bridges and different X-10 sensor and actuators networks and the possibility of controlling the system with a Wiimote. To the best of our knowledge it is very difficult to get an home automation installation as affordable as this one that provides not only the typical automatism services but advanced multimedia capabilities and the possibility of controlling the system from a web browser, a Wiimote controller or just the voice. Besides, the installation can be augmented with the time without troubles thanks to the plug and play nature of the standard. There are many manufacturers that offer UPnP devices that can be integrated, specially in multimedia applications, as Nokia [25] with their N95 mobile phone or Philips[26] with their RC9800i, to cite a couple of examples.

Given the versatility of the system it is also possible to face projects with much higher requirements. The price in these cases will be higher, specially in the cases where wired systems are used and building work is required.

In [27] some videos are shown to illustrate some of the benefits a well integrated home automation system offers. Precisely this integral point of view is what makes that the possibilities of the whole can be much higher than the sum of possibilities of the individual parts of the system. These videos have been recorded in real homes where the system has been successfully working for two years.

Finally, there is no doubt that there are still systems to be integrated under the Domoesi project's umbrella. In fact currently there are plans to develop bridges for other systems as KNX and Ingenium. However, given the UPnP modularity it is possible to enjoy yet a fully functional system composed by all the applications developed up to the present date.

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# Authors

**J. M. Maestre**, is holding a predoctoral research fellowship at the Universidad de Sevilla, Spain. In 2006 he received a Master degree in Smart Home and Buildings Technologies by the Universidad Politécnica de Madrid. In 2005 he received his master degree in Telecommunications by the Universidad de Sevilla. His research activity focused in the control of distributed systems and the interoperability in the smart home.

**E. F. Camacho** is a Dr. Electrical engineer from the University of Seville where he is now professor of the Department of System Engineering and Automatic Control. He has written the books: "Model Predictive Control in the Process industry" (1995), "Advanced Control of Solar Plants" (1997) and "Model Predictive Control" (1999) , (2004 second edition) published by Springer-Verlag and "Control e Instrumentación de Procesos Quimicos" published by Ed. Sintesis and "Control of Dead-time Processes" (2007) published by Springer Verlag. He has served on various technical committees of the International Federation of Automatic Control (IFAC). He chaired the IFAC publication Committee (2002-2005) and he is currently chairing the IFAC Policy Committee (2005-2011). He chaired the IEEE/CSS International Affairs Committee (2002-2005). He was the president of the European Union Control Association (2005-2007). He was elected member of the IEEE CSS Board of Governors (2008-2011). He is an IFAC fellow. He has carried out review and editorial work for various conferences and technical journals. At present he is one of the editors of the IFAC journal, Control Engineering Practice, one of the editor at large of the European Journal of Control and Subject editor of the journal Optimal Control: Applications and Methods. He was Publication Chair for the IFAC World Congress b'02 and General Chair of the joint 44 IEEE Control and Decision Conference (CDC) and European Control Conference (ECC) held in 2005. He has acted as evaluator of projects at national and European level. He was appointed for four years Manager of the Advanced Production Technology Program of the Spanish National R&D Program. He was one of the Spanish representatives on the Program Committee of the Growth Research program and is now acting as expert for the Program Committee of the NMP research priority of the European Union. His main research interest are in the areas of model predictive control and solar energy, areas where he has participated and coordinated many research projects and authored and co-authored more than 200 papers in journals and conferences.