The Smart Home Concept : our immediate future

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Abstract **– This general paper aims at presenting the Smart Home concept. In this paper, we will detail a) The Smart Home concept b) The various networks infrastructures specific to the habitat c) Our concepts to model the habitat and to provide the most adapted services to the inhabitants. Contrary to the other projects, we direct our work towards a sensors approach and an ontology modelling of the Smart Home. Our work has the originality to take into account the real heterogeneity of information present in an habitat and use a Service Oriented Approach (SOA). We can say that our paper is a good overview to present what is a Smart Home and which are the necessary hardware and software components to make a Smart Home.**

I. INTRODUCTION

Smart Homes, also known as automated homes, intelligent buildings, integrated home systems or domotics, are a recent design development. Smart homes incorporate common devices that control features of the home. Originally, smart home technology was used to control environmental systems such as lighting and heating, but recently the use of smart technology has developed so that almost any electrical component within the house can be included in the system. Moreover, smart home technology does not simply turn devices on and off, it can monitor the internal environment and the activities that are being undertaken whilst the house is occupied. The result of these modifications to the technology is that a smart home can now monitor the activities of the occupant of a home, independently operate devices in set predefined patterns or independently, as the user requires.

Smart home technology uses many of the same devices that are used in assistive technology to build an environment in which many features in the home are automated and devices can communicate with each other. The root of this ability to communicate between devices lies in the use of the 'busline'. A busline is a cable that connects all the devices together and enables interconnectivity between devices in different room throughout the home.

With the important development of the internet and the high speed access (ADSL, satellite, optic fibre,…), the potential of home working and teleworking is becoming possible. So, since several years, lots of projects about smart homes are emerging. Those projects are oriented multi-media access (Internet access, telephony, video...), thermal comfort, safety. Smart homes are now dedicated to simplify the life of its inhabitants, to make energy saving, to provide comfort and security solutions. In recent project, it has been shown that the smart home technologies have reached a good state of maturity but the spreading is still marginal and mostly restricted to demonstration projects.

Here is a list of projects about smart home :

1. Adaptive House, University of Colorado: http://www.cs.colorado.edu/~mozer/nnh/
2. Carnegie Mellon's Intelligent Workspace http://www.arc.cmu.edu/cbpd/iw/index.html
3. Duke University Smart House: http://www.smarthouse.duke.edu
4. Georgia Tech Aware Home: http://www.cc.gatech.edu/fce/ahri/
5. Humboldt State CCAT: http://www.humboldt.edu/~ccat/
6. MavHome at University of Texas Arlington: http://mavhome.uta.edu/
7. Medical Automation Research Center @ UVA: http://marc.med.virginia.edu/
8. MIT House_n: http://architecture.mit.edu/house_n/
9. MIT Media Laboratory: http://www.media.mit.edu/
10. NC State Solar Center: http://www.ncsc.ncsu.edu/
11. Oberlin College: http://www.oberlin.edu/ajlc/ajlcHome.html
12. Smart Medical Home: http://www.futurehealth.rochester.edu/smart_home/
13. UNC Office of the Future: http://www.cs.unc.edu/~raskar/Office/

II. SMART HOME : A TECHNICAL APPROACH

In a schematic way, a smart home can be described by a house which is equipped with smart objects, a home network make it possible to transport information between objects and a residential gateway to connect the smart home to the outside Internet world. Smart objects make it possible to interact with inhabitants or to observe them.

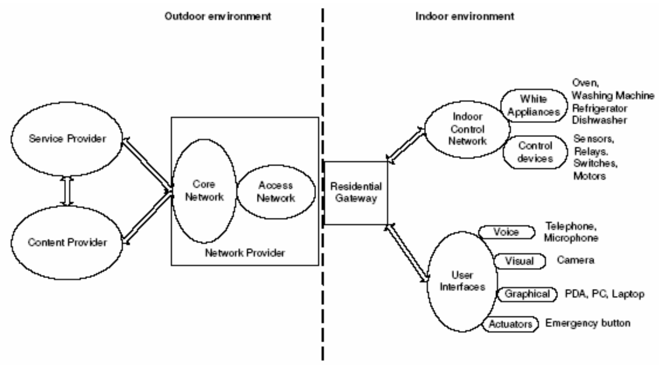

Figure 1 : The Smart Home concept [2]

Those smart objects can be just a light that we can control or ask it about it state, a refrigerator which knows its state and is able to supply in line by itself, telephony, security systems, videos on demand, …All those object will be connected on the home network to give their states or receive instructions. Home networking allows the home to become fully connected, controlled externally as well as internally. The residential gateway offers an extern access by the way of Ethernet or Internet network. This gateway makes it possible to the house to connect new services and to download them. The service provider is in charge of the new services for inhabitants and their accessibility.

On Figure 1, we can see what a smart home is. On the indoor environment, a smart Home is composed with white appliances like washing machine, refrigerator, some control devices like sensors, motors and user interfaces like voice, visual or graphical. In this smart home, we find the residential gateway which make it possible to connect to the outside Internet world

On the outdoor environment, we find the service provider which is in charge to provide services to the inhabitants and the network to provide communications between the smart home and the provider.

III. AVAILABLE TECHNOLOGIES IN COMMUNICATION DOMAIN

In the communication domain for smart home, we find two needs. The first one is how to make possible the communication of the equipment inside the house. The second one is to connect the smart house to the outside Internet world.

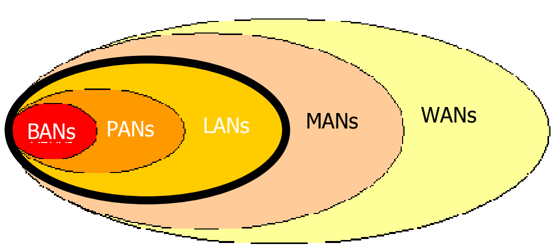

Figure 2 : Different kind of Area Networks

On Figure 2, we see five different kind of Area networks. The first one, WANs (Wide Area Networks), generally consist of satellites or antennas installed on towers or on buildings. They serve great geographical areas. These networks can be served by satellite or terrestrial cellular technologies or by fixed solutions without wire.

The second one, MANs (Metropolitan Area Networks) serve an area, for example the customers of a district.

The third one, LANs (Local Area Network) serve the personal needs for an individual who is responsible to manage his own network.

The fourth one, PANs (Personal Area Networks) serve the needs for a user with close objects such as a mobile telephone.

The fifth one, BANs (Body Area networks) are a continuity of the personal network, but on a smaller scale. This type of network is mainly based on the principle of smart objects localised on the body and, even in the body of the user.

WANs and MANs are used for outdoor environment. For the WANs, we find the UMTS, EDGE, GPRS or satellite technologies. Those technologies are wireless (WWANs : Wireless Wide Area Networks) and are able to transmit information at a distance of up to 30 Kilometers. For the MANs, we find WIMAX which is able to transmit information at a distance of up to 20 Kilometers

LANs, PANs and BANs are used in indoor environment. For LANs, Wifi and HyperLan are mainly wireless solutions. Ethernet is the main wire solution.

For PANs, Bluetooth, RFID, Zigbee, UWB are wireless solutions. CEBus, Convergence, emNET, HAVi™, HomePNA™, HomePlug™, HomeRF™, Jini™ technology, LonWorks, UPnP, VESA, USB and serial link are wire solutions.

For BANs, few solutions are existing now. We can note BodyLAN solution who use the skin to transmit data.

We will focus on indoor solutions to transmit data. For the communication in smart home, we will focus on PANs because they are the most adapted in term of distance and flow. We can find residential networking standards and initiatives that we are going to develop.

Bluetooth (IEEE 802.15.1) is the well-known technology used in mobile telephone and other objects (printer, digital camera,…). It is a set of protocols for the design of systems that allow radio frequency control over the system. Bluetooth enables devices to be connected together within a short distance.

RFID is the technology which is currently in full rise using of passive or active labels to store information there.

Zigbee (IEEE 802.15.4) is a wireless standard of data transmission allowing the communication of machine to machine (M2M). Zigbee is domotics-oriented with a very low fuel electric consumption which makes its principal asset to be used in smarty objects.

UWB is the wireless version of the USB and must make it possible to make communicate our current objects USB without wire at short distances (approximately 10 meter).

Those technologies are based on existing computer technologies. Nevertheless, we can find standards dedicated to the habitat.

First, Busline technology involves the use of a cable which are present into the home. The data is transferred through the cable to the devices enabling the devices to communicate with each other.
Many companies are now developing Powerline equivalents with many different protocols. The most important are BatiBus, CEBus, EIB, LonWorks and EHS. All those companies are fighting with each other and among them is no compatibility.
But recently, the Konnex Association [7] tried to make a common standard, the Konnex-KNX standard, which will unite the three current European alternatives: BCI (Batibus Association), EIBA (EIB Association) and EHSA (European Home Systems Association). In United State, we can find the Cebus standard and in Japan, the HBS standard.

Another standard is the X10 standard is the most common and easily form of smart home technology [6]. This technology is computer centered and devices can't communicate with each other. The device receives its instructions from the computer

BACnet - A Data Communication Protocol for Building Automation and Control Networks [8]. Developed under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), BACnet is an American national standard, an European pre-standard, and an ISO global standard (ISO 16484-5). BACnet is an open standard which is at the moment is striving to gain acceptance by the industry.

LonWorks [9] devices communicate with one another using the protocol that underlies the LonTalk. This implements a system that has established itself as a de-facto standard for building control and automation. Currently, millions of devices have been installed worldwide in thousands of LonWorks solutions. Since 1999 Echelon Corporation opened the LonTalk protocol by releasing a downloadable reference implementation of this protocol for use on any processor.

On Figure 1, we can denote some sensors in the smart home. This is the part on which we will focus. Those sensors make it possible to the smart home to observe on itself. With sensors, the smart home can determine what the best service is to provide to the inhabitants. This is what we call a context awareness system.

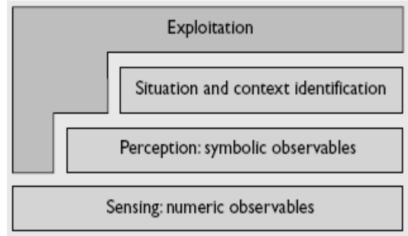

Figure 3 : Necessary abstraction levels for context awareness system [1]

IV. OUR SOFTWARE APPROACH

A. The concept of context

To provide the more adapted service, it is necessary that the system observes the inhabitant and collects information on its environment. To adapt the service to the current situation, it is necessary that the system is sensitive to the elements surrounding the inhabitant. It is what we call a context awareness system. The context is " all information which can be used to characterise an entity " [3] . Moreover, the definition that we adopt is the definition formulated by Gaëtan Rey in [5]. It defines the context concept as a whole of circumstances in which an action is, or which surrounds a fact and makes it possible to understand it. Thus, he defines that an interactive system is context awareness when it is able to identify the circumstances surrounding the action (and in particular the user action) in order to offer an adapted service. On Figure 3, Joelle Coutaz [1] presents the necessary various abstraction layers to the development of a context awareness system.

To determine a context, it is important to characterise information coming from this context. For that, it is necessary that the context awareness system is fed in contextual data which having a semantic level. Those contextual information represent the environment and are perceived in it. When we speak about perception, we are directed towards the use of sensors which make it possible to quantify a physical phenomenon. Thus, thanks to various sensors, it is possible to perceive the activities resulting from the environment of the inhabitant, *i.e.* in the smart home. Thus, we can say that the context perception architecture will make it possible to acquire contextual information relating to the inhabitant and his environment thanks to heterogeneous sensors in order to provide relevant contextual information. Concretely, we represent our context perception system in the following way:

On Figure 4 , we distinguish three steps. The lowest part of our architecture relates to the sensors. It is on this layer that the contextual data acquisition is done thanks to the sensors.

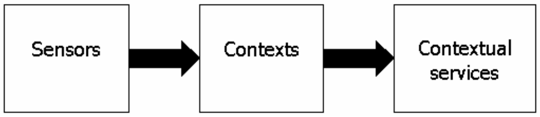

Figure 4 : Architecture for context perception

Then, a second part relates to the context. This part is charged to exploit the contextual data in order to provide higher semantics information. The third part relates to the use/management of these contextual data.

B. The concept of service

As we saw, we have to provide contextualised services to the inhabitants. To achieve that, we will be a services supplier. The role of the services supplier is to provide to its customers the services to which they subscribed. For that and with facility preoccupations, the deployment of the service chosen by a customer is carried out remotely. The deployment of the service is carried out on the residential gateway which becomes a services platform. A service is a definite behaviour in a contractual way and in which the contract is filled by a services supplier. The service oriented approach is focused on the description and the organisation of the services to support their dynamic discovery in execution time. In this approach, the appearance or the disappearance of the services during the execution can be taken into account. This dynamic availability makes it possible to build applications being able to adapt to various situations such as the context awareness.

C. The OSGi Platform

OSGi [4] is a specification defines by OSGi Alliance, which conceptualises a platform of services deployment with remotely administration. The reference implementation is done on Java, which enables its installation on any system. OSGi is mainly intended to be set up on embedded gateway like the domestic gateway previously seen. This platform offers a standard environment for the applications called Bundles and offers various services such as the management of the Bundles cycle of life (install, uninstall, starting, stop and actualisation) in a dynamic way without needing to carry out a complete restarting of the gateway. Bundle is a file containing a description file and a Java classes package, access code to the material and various resources. Under OSGi, a service is composed of one or a whole of bundles. The main goal of the services oriented framework OSGi is to benefit from the capacities of platform independence and dynamic loading of code of the Java language to facilitate the development and the dynamic deployment of applications for embedded systems.

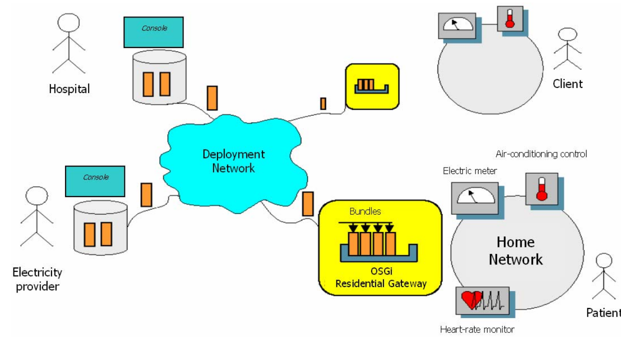

Figure 5 : Example of services deployment

On Figure 5, we have an example of bundles deployment. The doctor of the hospital wishes to know the health of his patient. For that, he deploys a bundle which making it possible to record the physiological data of its patient (here of the cardiac data) and sends on the network, the data which will be posted on the console of the doctor. In the same way, the electricity provider wishes to remotely raise electric consumption of his client. To do that, it deploys a bundle making it possible to read the electric meter and to send data towards the electric operator.

Thus, several bundles can coexist together without interfering their behaviour of it. This is the main advantage of the OSGi framework, several services in the same time and the dynamic deployment of services.

D. Our architecture for context perception

We define the PCIA Model (Perception-Context-Inference-Action) to take into account the context in the smart home. We will see the layers which we consider necessary to the development of our PCIA Model.

On Figure 6, we can see our architecture to make our PCIA model. We will see the different layer of our architecture. In the first part, we start by studying the lowest layer of our architecture, the perception layer. The second part will present our methods to use contextual information and to go up in semantic level to provide the more adapted service to the inhabitant.

This middleware takes as a starting point works of Sumi Helal team [12]. They present a programming architecture for pervasives spaces. The major difference with our architecture resides at the level of the event-driven layer.

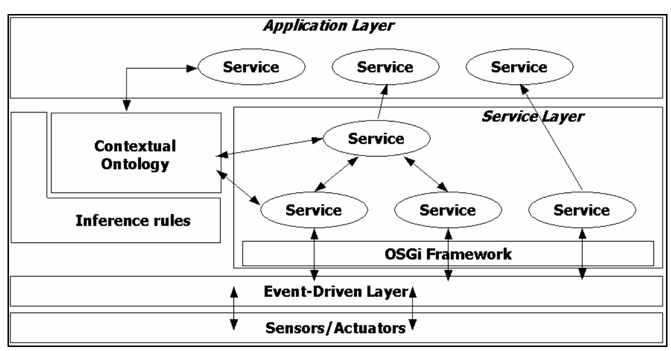

Figure 6 : Services oriented architecture for context perception

Perception Difficulties : Currently, the existing sensors we can obtain provide various data according to a specific protocol of their manufacturer. Then it is problematic to find a generic model adapted to each sensor. We add an abstraction level in order to have a unified layer of data sensors. We base our layer on the IEEE 1451 standard [10] aims at defining a standardised interface for the sensors networks. This makes it possible to automatically configure the sensors by integrating in them a specific interface and a function of auto-recognition.

How to convey information?

We have a sensor network, so we must wonder how the sensors data can be conveyed on this network. On this one, we find sensors (producers) and entities which needing these data (consumers). The sensors produce data on the network and the consumers use data present on this network. This policy is based on the software bus concept which allows a communication of group. A software bus makes it possible to manage a dynamic whole of entity which can appear or disappear from the bus. This concept of dynamicity corresponds to the constraints of a sensors-based system because it is possible to add or withdraw a sensor (when there is a failure, for preventive maintenance, to update....). In our case, it is preferable to use this bus in asynchronous mode [11]. Indeed, as the sensors data are strongly heterogeneous, the data will be provided on the bus in a random manner. In order to not scan the bus permanently, it is more judicious to be informed when an interesting data was publish on the bus. Coupling between producer and consumer is weak with such strategy. The *publish/subscribe* model is a communication model which is appropriate for our architecture where it is necessary to add the events concept that we can find in the event-driven model.

Figure 4 illustrates the Publish/Subscribe model. We see two producers (sensor_1 and sensor_2) providing data (A and B) to the bus mediator (charged to manage the exchanges on the bus). The role of the mediator is to manage the subscriptions at an event, their reception, their filtering, and their routing towards the interested consumer.

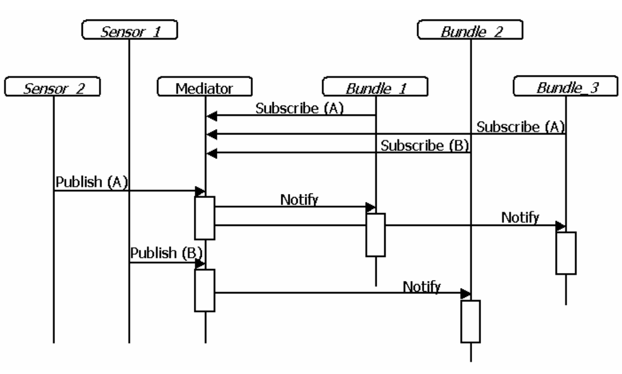

Figure 4 : The Publish/Subscribe Model

Events emitted by the sensor layer : The sensor layer is in charge to emit events corresponding to information of the environment. The event emitted by the sensor layer is based on the IEEE 1451 standard and takes the following form:

- SensorValue: The value provided by the sensor.
- TimeStamp: Time-stamping makes it possible to know the moment when the event was emitted.
- SensorUnit: Represents the class of information provided by the sensor (Temperature, presence...).
- Uncertainty: This data makes it possible to obtain a value reflecting of the uncertainty of a sensor measurement. This uncertainty represents a probability acquired with previous treatments
- SensorID: Single sensor identifier which is transmitting the data.
- MsgID: Single identifier of the transmitted message. This identifier is incremented after each sending of message. It makes it possible to a consumer to be unaware of old messages which would have been lost on the bus.

We saw the sensor data acquisition part and their distribution on the event-driven bus. We now will present the higher level part which is in charge to use the sensors data.

We propose to exploit the architecture of context perception described previously and making it possible to reason with the contextual data. It integrates the inhabitant services concept. From the collected contextual data, the system will provide the adapted service to the inhabitant. These services will result from a phase of decision.

The service layer : The service layer gathers three types of services. The basic services which have in charge to provide contextual data from sensor. The composite services which have as roles to aggregate a whole of contextual data in order to provide data with a more important semantics.

The contextual services are services provided to the inhabitant based on the information observed in the environment. The contextual services can use the data resulting from the basic services or the data resulting from the composite services. The contextual services are to be considered on the level of the application layer.

The context model : To model this context, the majority of work use an object oriented approach of the context or a textual representation of the context. Our context model is articulated around an ontology which makes it possible to model the smart home. This ontology provides the physical representation of the smart home (carries, wall, window...) as well as the objects of the smart home (furniture, electric appliances,...). In the same way, this ontology makes it possible to represent the inhabitant by modelling his characteristics and his preferences (localisation, identification,...). Thus this ontology is supplemented by contextual information coming from the sensors. It makes it possible to obtain a representation of the inhabitant and his environment at one moment. By using an approach based on ontology, we obtain a formal representation of the context and reasoning methods on the contextual data. [13] presents a context representation and reasoning on the contextual data being based on an ontology. An approach based on ontology for pervasive computing is presented in [14] within the framework of Web Services supplying. The context information are expressed in RDF and by OWL ontology. This work proposes the possibility to the ontology to be extended in the case of the addition or the withdrawal of element.

Ontologies are based on the OWL language, suggested by the W3C, and which offers a greater capacity of interpretation of the contents of the model than XML, RDF and RDF diagram (RDF-S). With an additional vocabulary and a formal semantics, OWL makes it possible to applications to treat the contents of the model. Thanks to OWL, it is possible to represent the significance of the terms of vocabularies and the relations between these terms. One calls ontology, this representation of terms and their interrelationships. In our case, ontologies will enable us to model in a formal way the context in the smart home and to proceed to inference phases. Our ontology is written under the Protégé Editor[1].

Contextual inferences rules : Reasoning on the contextual data will make it possible to insert a layer of artificial intelligence into our architecture and to create high level contextual data starting from low level contextual data. Let’s take the example where we have Jean present in his room, lengthened with the light off. We can starting from a simple rule defines that Jean is sleeping. Information ' Jean is sleeping’ is high level contextual information whereas information ' Jean is in the room', ' Jean is lengthened', ' the light is off ' are low levels contextual information. With a whole of rules, it is then possible to define high level contextual information and to provide the more adapted service to the situation in progress. We think that first order rules are sufficient to describe the context.

We use SWRL to manage our ontology. SWRL is a proposal of the W3C aiming at unifying OWL and rules of logical inferences. We choose the KAON2 API to interact with the OSGi framework.

V. CONCLUSION

In this paper, we present what a Smart Home is. We present which components are necessary to make a Smart Home. First, we need a network infrastructure to convey information emitted by heterogeneous smart objects. Second, we need a software architecture to use information. To achieve that, we use a service oriented approach to manage information and to provide the more adapted service by the way of heterogeneous sensors. To manage sensors information, we first use a publish/subscribe bus and an ontology to model and infer with contextual information.

VI. ACKNOWLEDGMENT

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