A REAL-TIME NETWORK BASED ON IEEE 802.15.4/ZIGBEE TO CONTROL HOME AUTOMATION ENVIRONMENT

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Abstract

The use of wireless technology in home and buidilng automation systems has recently been increasing due to several advantages such as cost reduction, easy placement and installation, easy extension, comfort benefits, and mobile device connectivity. Among the many wireless technologies available ,IEEE 802.15.4/ZigBee is one of the most useful for home automation. A wireless home networking system can be configured using ZigBee alone. This paper shows an architecture that uses the wireless protocol 802.15.4/ZigBee in a Home Automation and where it is necessary to transmit traffic flows of time-critical control data between sensors and actuators and automation network.

I. INTRODUCTION

Consumer electronics technologies such as home networking and automation technologies is rapidly changing due the recent development of ubiquitous computing. One of the most promising protocols for wireless home networking and automation is ZigBee [1, 2], a de facto standard for WSNs (Wireless Sensor Networks). The diffusion of this wireless tecnologiy is due to its low power consumption, low cost, and support for various cluster automation network configurations [3]. IEEE 802.15.4 protocol [4, 5], which describes MAC and Physical layer of the ZigBee [2] protocol stack, is thought up to be used in special purpose systems, since they need low consumptions and do not necessitate an high transmission speed; specifically, we are talking about implementation without time tie. One of the most main features for home gateway systems is to support flexible interoperability between home network applications and various ZigBee/IEE 802.15.4 cluster network formed by simple consumer devices such as wireless sensors, appliances, and mobile consumer devices.

In literature many papers [6 – 8] show the potentialities and the features that make it really attractive to the Real-Time applications: in fact, IEEE 802.1.5.4/ZigBee could be used in a lot of areas, such as Home and Building Automation, Tele Management, Infomobility, Factory Automation [9], Telemedicine, telecommunications, WSNs. One of the most important requirement of a Real-Time System is the predictability, without which the System become unstable. Not always, though, the physical channel used to transfer the data is suitable to support such a high rate of reliability in particular, wireless channels, because of their weakness in relation to interference, have the characteristic of being unpredictable.

Because of its peculiarities, a wireless infrastructure with appropriate countermeasures may be used for Soft Real-Time applications, however are unfeasible in case it is needed to implement an Hard Real-Time system of in which even one deadline miss can have serious consequences, if not catastrophic. Given the need to have guarantees of determinism, it is preferable to implement a centralized access protocol type, rather than a random access such as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), in which case you may have only probabilistic guarantees and not deterministic. IEEE 802.15.4/ZigBee, however, can achieve an hybrid approach of centralized master/slave and that of CSMA/CA, exploiting the advantages of a centralized policy with access to the channel regulated by a central node called PAN Coordinator (PC), which allows the implementation of a scheduling policy from which is possible to allocate up to 7 Guaranteed Time Slots (GTS) in a deterministic way during the phase called Contention Free Period (CFP).

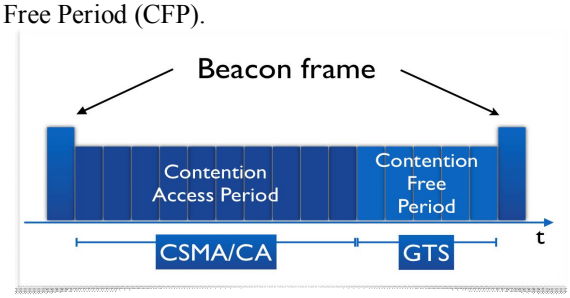

Fig. 1. IEEE 802.15.4 MAC with beacon enabled

Thanks to the algorithm CSMA/CA, implemented in the phase called Contention Access Period (CAP), is also possible to resolve the starvation of non Real-Time activities, that is the situation where a node cannot access the channel because of its low priority or due to the unavailability GTS.

The paper is organized as follows. In Section II will be discussed the requirements of home and building automation systems. Section III describes the system models and network architecture used in this paper. In Sect. IV we introduce some simulation scenarios to validate the results obtained from the metodology decribed in this paper. Finally, Sect. V summarizes the paper and discusses future work.

II. REQUIREMENTS OF AN HOME AND BUILDING AUTOMATION SYSTEM

An Home and Building Automation System [10] should follow a requirements fixed schedule in order to improve existing conditions. In general, they are grouped into the following five broad categories:

1) Safety: intended as protection from possible malfunction of equipment potentially dangerous or harmful to people and housing. For this purpose, are used fire protection systems, sensors, anti-flooding, loads of power transmission, sensors that regulate the gas leak;

2) Security: that is the control of the access, physical and computerized, from the outside. The first control is delegated to burglar alarms and access control systems. Computer attacks, since they are coming from the external network (eg. Internet), are managed by several technologies such as MAC, Firewall, Proxy, as well as through access control using identification codes;

3) Energy saving: under which fall all the techniques and systems capable to optimize energy consumption. Designing a system able to source the cheapest energy source is one of the first objectives as guarantees of affordability;

4) Comfort: collects all the tools to simplify and make easier the livability within the home, ensuring that the level of perceived occupant comfort is as high as possible. Within this category also includes ease of use of the various Home Automation System functions;

5) Stability: namely the system ability to react to failures of individual modules in order to avoid mistakes that could compromise the functioning of the entire automated environment.

Home and Building Automation is applied to a wide range of products and systems in the home:

- Appliances: refrigerator, freezer, washing machine, dishwasher, oven, vacuum cleaner;
- Audio-video systems: Home Theatre, DVD, Blu-ray, HDTV, Home Entertainment;
- Lifts, hoists;
- Night lights and safety;
- Network systems: electricity, network video surveillance, telephone network, Internet, gas network;
- Security against fire, intrusion, gas leaks, water leaks, electrical leakage and short circuit, blocking the lift;
- Assistance and aid to disabled person, elderly and children.

This paper aims at the Real-Time control of a network based on IEEE 802.15.4/ZigBee in a scenario that simulates the following features.

- Domestic environmental monitoring [7]. Thanks to the sensors, placed inside and outside the house, we can monitor current weather indexes of any area of the dwelling;
- Energy consumption monitoring. Leveraging the integration between the various components, it is possible to minimize energy consumption: for example, you can turn off the lights of a room where attendance is not being collected, rather than diminish the intensity when the natural light coming is already sufficient to illuminate the room. The network architecture proposed operates so as to ensure that the electrical load does not exceed the limit imposed by contract for electricity. Among the devices available for the Home Automation Systems, there are several devices that are able to instantly report the power consumed, so we can stop the supply of electricity to some lines in order to not exceed the limit imposed.
- Alarm management aimed at preserving the health and safety of occupants of the dwelling. The house is equipped with sensors able to report a gas leak or water loss, as well as the principles of fire and the presence intruders. The use of these components makes the building safer for those who come inside, ensuring total control over it.
- The system is also able to monitor the health of an inhabitant of the automated home, in order to inform relatives or relief agencies when necessary.

III. SYSTEM MODEL

The idea behind the Home Automation System analyzed in this paper is to control and supervise the whole devices in the house both locally and remotely, and this has led to a two-tiered network architecture.

The system described here is designed to monitor and control various types of devices connected to home automation.

The System can know in real time the status of the various apparatus and act on them through direct or planned operations by the user.

Who live in this kind of house, using this environment of Home Automation, can control any device, checking its functionality, its current situation and deciding to act immediately to change its state. In addition, the System offers the ability to schedule

operations to be executed at a certain hour with occasional or regular basis.

This System includes all the features associated with an Home and Building Automation, regarding safety – through the presence of sensors that measure various biological parameters – security – monitoring the presence of intruders in the house – and comfort. The System is based on sensors and actuators with IEEE 802.15.4 nodes directly connected to the PAN Coordinator, which in turn are connected together by wired infrastructure. Those sensors are located in different focal points of the house and directly connected to household appliances, HVAC (Heating, Ventilation and Air Condition) systems, video surveillance cameras.

To provide the control feature of older people, however, the person to be monitored should carry an accelerometer, so that the System, by using a camera. could be able to identify its state (standing, sitting on the ground) and to detect a dangerous situation, notifying the controller connected to the Internet. These notifications can be sent through Internet to a specialized center or emergency and over GSM to a relative.

The simulated results of the conditions of ambient lighting will be implemented through internal and external devices RFD (Reduce Full Function) IEEE 802.15.4/ZigBee with sensors positioned near the internal and external lights; changes in lighting conditions inside will be implemented thanks to the commands sent by an actuator directly to the lights. Changing climatic conditions will be simulated (by software) from the PAN Coordinator IEEE 802.15.4/ZigBee, while the internal temperature sensor is positioned inside the rooms to be monitored. The emergency lights, placed in every room and always fed, are governed by the PAN Coordinator of the network which covers the room where they are located. The lighting in every room, which also includes the handling of blinds and awnings, will be disabled if not detected any presence. The presence of people is detected by appropriate sensors presence. In case of overloading of electrical power, will be turned off the power. However, the presence detection system will be able to correctly interpret the inputs from unauthorized intrusion, even if the power is turned off.

Regarding the Heating, Ventilation and Air Conditioning System (HVAC), it is driven on the basis of two different temperature levels (home, comfort) through the internal temperature sensor, external temperature sensor. As a general rule, the temperature "Comfort" is reached by activating the fan at medium speed, while switching from "habitation" to "Comfort" occurs through activation of the fan at high speed. All presence and intrusion sensors, both passive or active, are not directly connected to the rest of the network, but they constitute a separate cluster managed by a PAN Coordinator 802.15.4/ZigBee.

The Presence Detection System causes a local signal by siren and send the alert via the Internet and telephone network, in addition the system will turn on the lights of every room. It is based on volumetric presence detectors, equipped with passive infrared; also, it is possible to install one contact magnetic position detector on the frame of each window and/or door. By using a network of sensors and actuators forming a cluster, you can ensure environmental safety technology (safety).

Description of the network architecture

Fig. 2 below shows a scenario in which several clusters, each on the control of specific activities, are interconnected through a wired backbone.

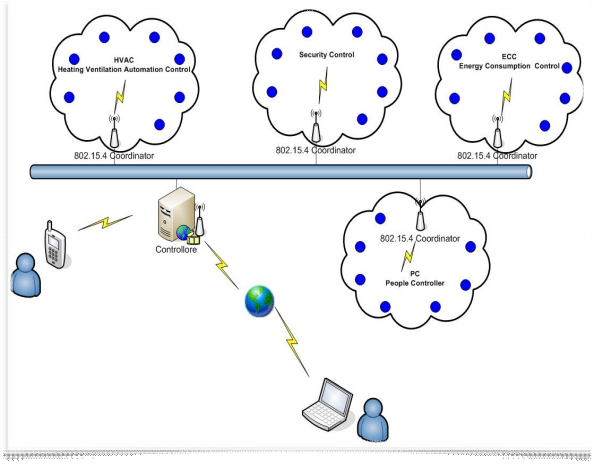

Fig. 2. Two-tiered network infrastructure for Home and Building Automation

A proxy, so in [12, 13], is implemented to ensure the interoperability between ZigBee network and the wired backbone. Using a computer equipped with the Wi-Fi [13] interface, directly connected to the Internet, it is possible to control, both locally or remotely - all devices in the home. As shown in fig. 2, the proposed system consists mainly of four types of nodes:

– 802.15.4 PAN Coordinator, which is responsible for interfacing with the wired backbone and the wireless cell and, finally, it monitors the whole Automation through the nodes of the PAN;

– Sensors and actuators, which consist of 802.15.4 nodes; the first measure various parameters, then send the PAN Coordinator. The actuators, instead, comes into operation when receiving the command from the PAN coordinator;

– Network Controller, which is a node connected to the wired backbone, also equipped with wireless interface; it has the task to incorporate the information given by the user which are then translated into commands to be sent to the PAN Coordinator.

Remote users can access the system via the Internet or through an application for iPhone/iPad that allows them to manage all the devices, even when not at home. The Home and Building Automation System based 802.15.4/ZigBee is used to monitor and control all devices for domestic use (fig. 2).

IV. PERFORMANCE EVALUATION

The automation cluster control based on IEEE 802.15.4/ZigBee has been simulated using OMNeT++ (Objective Modular Network TestBed in C++). It consists of three kind of Automation Cluster Network (ACN).

The first ACN simulates the Heating, Ventilation and Air Condition automation (HVAC) control. The second ACN manages the electrical plant by monitoring the energy consumption. Finally, the last CAN, deals of plumbing monitoring.

During the network initialization phase, each PC analyzes the current channel state to chose the best transmission channel, in order to reduce the co-channel interference. The simulated scenario uses a two tiered network composed by two wireless technologies (Wi-Fi [13] and IEEE 802.15.4 [4, 5]), so it is necessary to manage the channel scan phase to exclude ranges of frequencies used by IEEE 802.11 [13] protocol.

The proposed architecture was evaluated both quantitatively and qualitatively; in order to demonstrate the feasibility and effectiveness of the automation methodology proposed, we have simulated three networks, represented in the following figures.

Without loss of generality, assume that each ACN could be a cluster tree WSN. In this sense the PC collects the data sent from the router of the WSN.

All control activities are regulated by a time-triggered mechanism, different processes control periodically interrogate the home-devices. The management traffic flows are characterized by a period and a deadline. While a set of event driven process are implemented to manage some aperiodic activities.

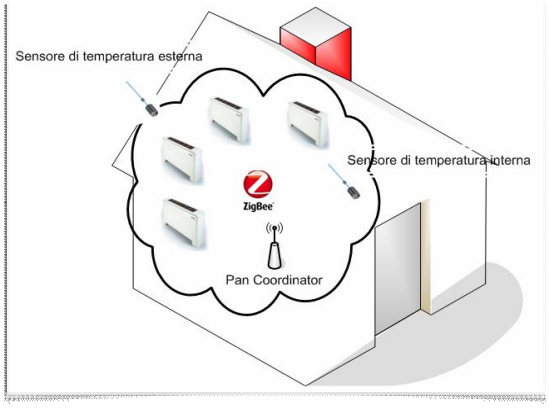

Fig. 3. HVAC automation cluster

The network cluster shown in Figure 3 manages the HVAC System. The PAN Coordinator node adjusts the fan speed according to the following factors:

– Data collected by the internal and external Temperature Sensors;

– Data collected by the Presence Sensor located inside the room;

– Type of room. bedroom, living area, etc;

– Temperature profiles configured by the user.

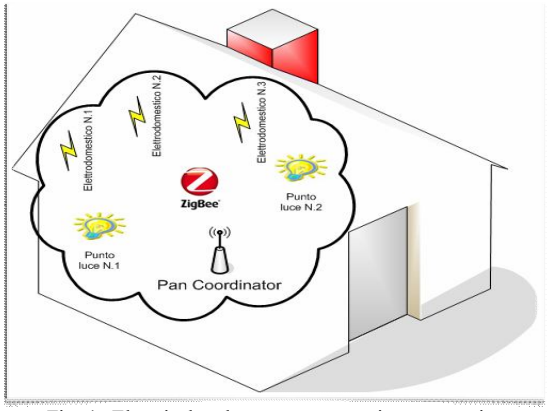

Fig. 4. Electrical and power consumption automation cluster

In the second ACN, shown in fig. 4, here simulated, the Pan Coordinator periodically receives the information that indicate the effective energy consumption for each electrical device. It uses a scheduling algorithm to maganag the electrical overload. This methodology (shown in fig. 5) is necessary to decide which devices has to be turn off when the energy consumption exceed the maximum tolerated value (previously chosen by the user).

```
Manage_overload(){
      do {
            Unit_OFF = search(priority_low, ON_units)
            power_consuming = get_power(unit_OFF);

            if(unit_OFF == lights && sensor_presence == true)
                  power_consuming = 0.0;
            else off(unit_OFF);
      } while (get_power(now) - Power_consuming <= threshold)
}
```

Fig. 5. Algorithm Code

The algorithm shown in fig. 5 exemplifies the Energy Consumption Automation Control, by understanding how the PAN Coordinator operates in several cases in order to fall within the maximum output power established by contract.

The PC also manages the brightness of different light sources using the data received from the twilight sensor, placed outside, and the light internal sensor.

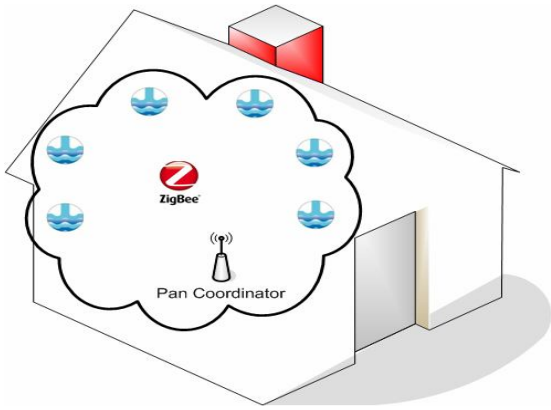

Fig. 6. Automation cluster

Fig. 6 shows the cluster that monitors the network of water control system; in the absence of the user and only if no devices need running water, it also disconnect the water supply to prevent loss or waste. However, it is important to specify that this automation is only used in order to detect water leaks and its behavior is tested in the whole network context. Long simulations were performed on this System in order to make the results comparable to the real.

The simulation results are summarized in the following plots (fig. 7 and 8). They show the desired temperature set by the user (expected value, the red line) and the actual temperature (measured value, the green line) of the room at regular intervals of 60 minutes, both in summer and in winter season.

The home user can indicate a desired temperature value for each room, specifying different value during the night and the morning or can set the values with a fine granularity for each hour for example.

The system provides to maintain a comfort temperature level in the home environment.

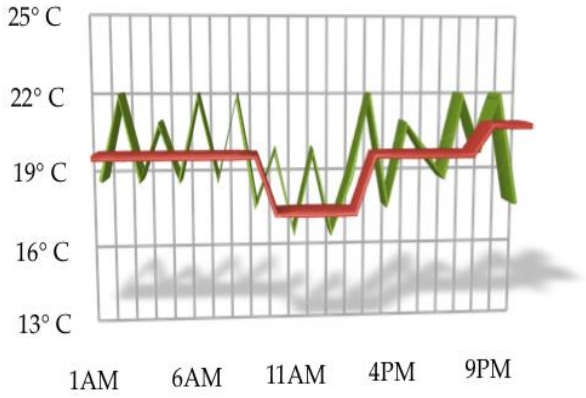

Fig. 7. Summer temperatures

The current temperature of the environment in winter reaches the desired value more quickly than it does in summer, since it depends not only on the Home Automation algorithm but also on the level of thermal insulation of the building.

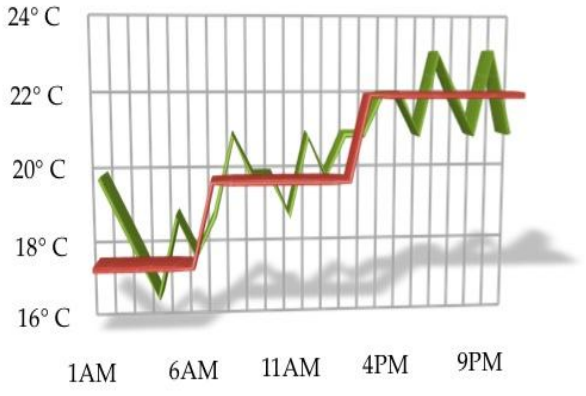

Fig. 8. Winter temperatures

The home user sets a threshold value, it is necessary to run the energy consumption IEEE/802.15.4 algorithm control (shown in fig. 5).

In our scenario the threshold was fixed equal to 2750W, beyond which the system decides which device should be turned off. This decision is made on data received from the presence sensor; therefore, the algorithm turn off the lights located in rooms where there are no people.

The following plot shows the event driven behavior of Home Electrical Device (HED). When HED turn on, occurs an event, the algorithm (fig. 5) calculated the actual value of energy consumptions, if it exceeds the threshold value, the system provides to turn off one o more devices.

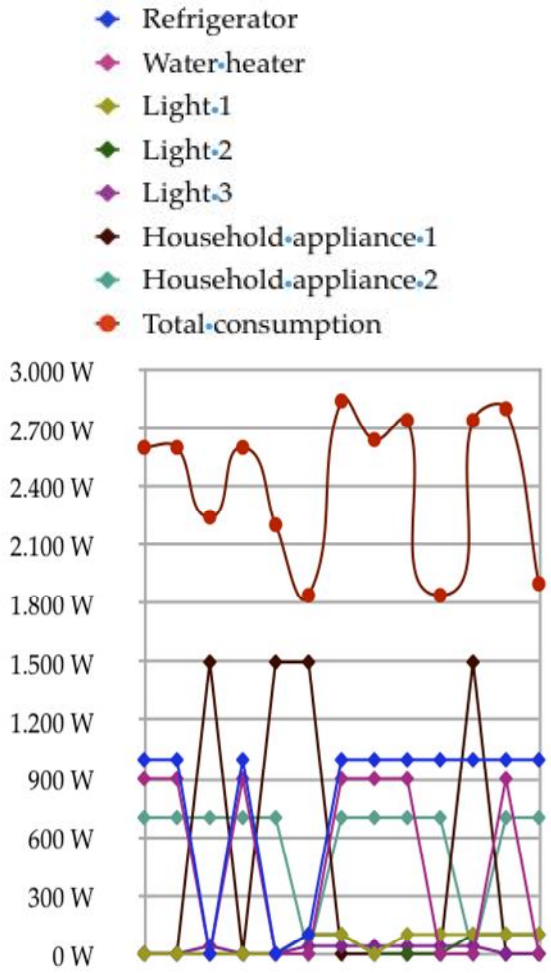

Fig. 9. Energy Consumptions

V. CONCLUSIONS AND FUTURE WORK

In this paper we described a two-tiered architecture designed to connect nodes that exchange messages with Real-Time constraints within a Home and Building Automation scenario. The architecture model here proposed solves the problems of limited transmission range of the IEEE 802.15.4/ZigBee protocol, allows to control and monitor the various devices in a centralized approach both locally and

remotely (using the Internet access). The architecture shown in this paper is being tested: we are going to implement a real testbed and we are analyzing the issues concerning the implementation of the user interface of the Home Automation System based on the requirements of the Interaction Design.

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