

Domotics Over IEEE 802.15.4 – A Spread Spectrum Home Automation Application

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Abstract— This work intends to demonstrate the use of IEEE 802.15.4, a low-rate spread spectrum wireless network protocol, to provide real time environmental sensing information to the Home Sapiens – a smart home simulator [1]. IEEE 802.15.4 focuses on enabling pervasive wireless sensor networks for residential, commercial and industrial applications. The standard is characterized by maintaining a high level of simplicity, low cost and low power, with high immunity at the ISM band due to its spread spectrum transmission techniques. This paper presents the simulator itself, a brief technical introduction of the IEEE 802.15.4 standard and analyzes its reliability in a real home automation application.

Keywords—IEEE 802.15.4; Spread Spectrum; Wireless Sensor Networks; Home Automation; Domotics; Control Systems; Smart Homes; Home Sapiens.

I. INTRODUCTION

This work presents a wireless sensor network data exchange interface to Home Sapiens, a smart home simulator. This simulator was created in 2004 in order to enable studies about intelligent houses, a subject that includes the interaction of several small electronic devices in a residential environment (a.k.a. Domotic Systems). The simulator itself, its interfaces and control systems are fully detailed in [1].

All the work presented here is based on that simulator. It has the purpose to add a data exchange interface in order to acquire external real time sensing information. In addition, it also provides a way to change the state of actuators and other electric-electronic devices in a real scenario through the graphical interface provided by Home Sapiens.

The original simulator emulates all the data exchanged between software-based sensors and actuators and the control systems. That approach depletes the simulation process hiding details which are usually observed in a real scenario. Here, a data exchange interface based on an IEEE 802.15.4 radio protocol is added, introducing rich detailed information about the interactions of people on a daily basis smart home living situation.

Initially, when this work started, Bluetooth was the first choice to build a sensor network, but it is too expensive and its

performance is not required. The other option was the low-cost power line carrier but it still shows serious reliability issues that limit the use of the technology. Power line also would need a mandatory gateway to communicate with mobile devices.

In order to make things clear, Section II presents a brief introduction to Domotics and the motivation for the use of wireless sensor networking in home automation applications. Section III presents a technical overview of the IEEE 802.15.4 standard, followed by Section IV where the original simulator is shown. Section V presents the proposal, challenges and the data interface itself. Conclusions are in Section VI.

II. DOMOTICS IN A GLANCE

Home networks (data, control and multimedia) and home automation devices have become increasingly important in the last few years pushed by the Internet and by mobile communications [2-3]. They not only provide better ways to transfer information within homes, but also they provide better time management too. In addition, they also improve the quality of our lives by automate some of the electrical home appliances [4]. On the other hand, all this smart stuff still needs great research in order to develop non-invasive, whole-time systems and devices, bringing real comfort and safety to smart house owners.

Devices to make homes smarter are not new; X-10 appliances have been sold since the late 70's. The benefits and features of smart homes have been highlighted again in the last ten years, supported by new technologies of home networking, re-introducing, after two decades, applications of remote control and monitoring in residential environment.

The use of such smart devices in a house and the immersion of people in an active computational environment allow several discussions and questions when the human behavior is analyzed. In this context, a young science as Domotics takes place, inheriting many ideas, viewpoints and techniques from other disciplines as Engineering, Computing, Artificial Intelligence, Sociology and Philosophy [5]. Domotics not only comprehends all technological subjects related to smart homes, but also concerns all sorts of user interactions in a 24-hour active computational environment.

The miniaturization of the smart appliances and a straightforward possibility of being connected to others devices have opened up a wide variety of new applications, motivating researches about subjects never thought before. With a bunch of new appliances surrounding users 24 hours a day, some paradigms had to be restructured. One example is the man-machine interfaces that have been remodeled in order to promoter a better interaction by any user inside the house, including elders, children and any person with some kind of disability.

Nowadays, home automation has also been pointed out as a tool for a rational and efficient use of energetic resources in a water, oil and electricity scarceness era. The control systems have been optimized to cooperate with other systems to achieve maximum comfort, safety and efficient use of resources.

The reasonable prices of control system devices have stimulated its implementation in new situations. Smart home researchers have made the most of this opportunity developing applications to better use natural resources in a home, gaining notability of the scientific community.

The interest in using wireless sensor networking in home automation applications is to provide a common communication network to enable all the functionalities (e.g. energy conservation, environment control, lighting control, safety and security) in a house, since the characteristics of each of these functions need similar performance requirements. Other interest in applying a wireless scenario is to reduce installation costs (cabling, labor, materials, etc.) [6].

The terms “intelligent” or “smart” are used here for systems/devices that gather values and can be considered on a developed state (combining some autonomy level and decision taken), separating them from systems/devices on a simplest state. However, we don’t want to make any mention to human capacity or to offend the concepts defined in Artificial Intelligence or Cognitive Science. Commercially, these terms have been used to invoke new functionalities and features of equipments, appliances and services. But, really, many times they don’t effectively develop any kind of intellect or discerning.

III. THE IEEE802.15.4 STANDARD

In December 2000, Task Group 4, under the IEEE 802 Working Group 15, was formed to begin the development of a low rate wireless network standard. The goal of Task Group 4 was to provide a standard with the characteristics of low-complexity, low-cost and extremely low power for wireless connectivity among inexpensive, fixed, portable and moving devices [7]. The effort concluded in October 2003 with the ratification by the IEEE Standards Association of the IEEE Std. 802.15.4 [8-9]. In order to be used in a wide variety of applications with short-range distances and limited power, IEEE 802.15.4 assumes that the amount of data transmitted is short (minimal overhead over the transported payload) and that it is transmitted infrequently in order to keep a low duty cycle.

The standard allows the formation of two possible network

topologies for a Personal Area Network (PAN): the star topology or the peer-to-peer topology (see Fig. 1).

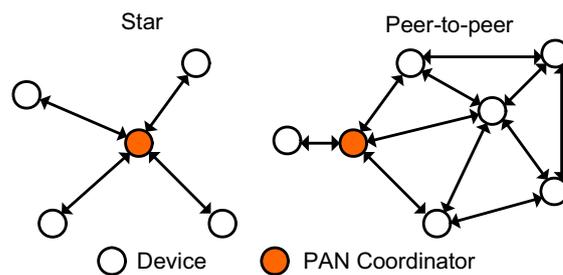


Fig. 1 PAN Topology

In the star topology, the communication is performed between network devices and a single central controller, called the PAN coordinator. A network device is commonly a simpler device with a simpler protocol stack. In the other side, the PAN coordinator is in charge of managing all the star PAN functionality. In the peer-to-peer topology, every network device can communicate with any other within its range. This topology also contains a PAN coordinator, which acts as the root of the network. Peer-to-peer topology allows more complex network formations to be implemented; e.g. ad hoc and self-configuring networks [10].

The IEEE 802.15.4 defines the PHYSICAL (PHY) and MAC layers. The network layer is defined by the ZigBee Alliance [11] and is therefore, not in the scope of IEEE 802.15.4 (see Figure 2 for the complete protocol stack).

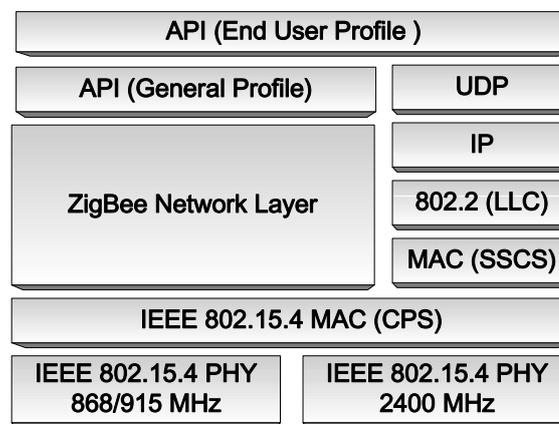


Fig. 2 Complete Protocol Stack

The IEEE 802.15.4 MAC sub layer provides access to the physical channel for all types of transfer and ensures the reliable transfer of the frames. It is a light weight simple protocol that is based on CSMA (Channel Sense Multiple Access). Its responsibilities may also include transmitting beacon frames, synchronization and providing a reliable transmission mechanism. A key aspect of the data link layer is that individual packets are each acknowledged thus providing link level delivery guarantees. However, there are no guarantees of quality of service, or support for priority levels of

network traffic. Essentially, IEEE 802.15.4 offers only best effort end-to-end delivery of individual packets.

The IEEE 802.15.4 physical layer was designed to support two frequency ranges based on direct sequence spread spectrum (DSSS). The first, in the low-band PHY, an 868 MHz band is specified for operation in Europe offering one channel with a raw data rate of 20 kbps. In North America, a 915 MHz ISM band offers 10 channels with a raw data rate of 40 kbps. The low-band uses binary phase shift key (BPSK) modulation. The second, the high-band PHY specifies operation in the 2.4 GHz ISM band, with nearly worldwide availability. This band spans from 2.4 to 2.483 GHz and offers 16 channels with channel spacing of 5 MHz, operating with a raw data rate of 250 kbps using Offset Quadrature Phase Shift Keying (O-QPSK) modulation.

The IEEE 802.15.4 standard specifies a receiver sensitivity of -85 dBm for the 2.4 GHz band and -92 dBm for the 868/915 MHz band. Practical implementations are expected to improve this requirement. The standard specifies a transmit power capability of 1 mW, although it can vary within governmental regulatory bounds. Both PHY layers use a common packet structure, enabling the definition of a common MAC interface. Each packet, or PHY protocol data unit (PPDU), contains a preamble, a start of frame delimiter, a frame length, and a PHY service data unit (PSDU) field. The 32-bit preamble is designed for acquisition of symbol and chip timing. The payload field is variable in length; however, the complete MAC frame may not exceed 127 bytes in length (see Fig. 3).

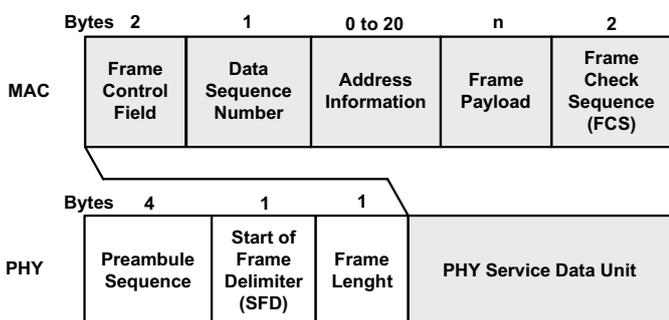


Figure 3 IEEE 802.15.4 Frame

IV. THE ORIGINAL SIMULATOR

Home Sapiens is a smart home simulator being currently developed at the Integrated Systems Lab of the Polytechnic School at University of São Paulo. The main purpose is the development of a tool to analyze control systems in a residential environment.

Home Sapiens is a Java-based software program which provides a graphic interface where the user can control and monitor several aspects of a virtual house. Buttons and slide bars are provided to let users change some external physical characteristics as climatic (humidity and temperature) and lighting conditions. It also has pop-up screens where the user can set parameters for each of the 14 control systems accordingly to the research perspectives.

In 2005, a new feature was introduced into the simulator adding another level of complexity to the process. Virtual beings were created and allowed to walk around the places inside the virtual house changing some characteristics of the control systems. A genetic algorithm [12] creates each virtual being, promoting a more realistic scenario; closer to what it would be expected on a daily basis for smart home monitoring events. The fitness function can also be adjusted in order to create agents with appropriated functions to each simulation routine. After the creation process, the virtual beings follow the rules modeled by a neural network that senses the environment and returns an action.

Fig. 4 shows the simulator main screen. On the left side there is the main floor plan of a virtual home being analyzed. The little geometric drawings represent the state of sensors, actuators and smart devices inside every room (a more detailed window is provided). A climate event generator and the monitor panel are at the right side. In the middle, a pop-up screen exhibits control systems buttons. Three virtual beings can be seen playing at the balcony, near the main entrance at the lower-left corner.

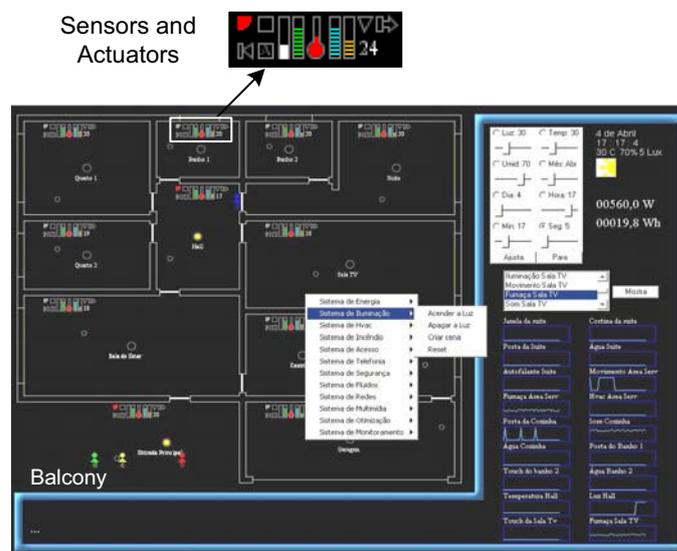


Fig. 4 Main Screen

In a smart home environment, there are many inputs and outputs being analyzed currently. To find the best approach – promoting the most of safety and comfort to user, keeping energy consume as low as possible - 14 control systems deal with several amounts of data coming from all the sensors installed over the rooms in order to send the most reasonable order to actuators.

A more horizontal, decentralized and dynamic control systems approach is being the focus of the next versions following the recommendations in [13-14].

The whole scenario gets more and more complicated when it is introduced user interactions, biometric data, location aware applications, several home networks, third-party software, easy access interfaces, etc. In order to put all these things together,

Home Sapiens has shown to be a great tool for helping researchers to build a reliable smart environment in the near future.

V. PROPOSITION

This work intends to add an external data interface to the Home Sapiens simulator allowing a real time sensing and state change of actuators of a smart home environment.

It was based on seven nodes containing an IEEE 802.15.4 radio transceiver, an 8 MHz, 8-bit microprocessor with 40 input/outputs for sensor/actuator connection and a residential ready-to-use 80-240V, 50/60 Hz switching power supply (Fig. 5).

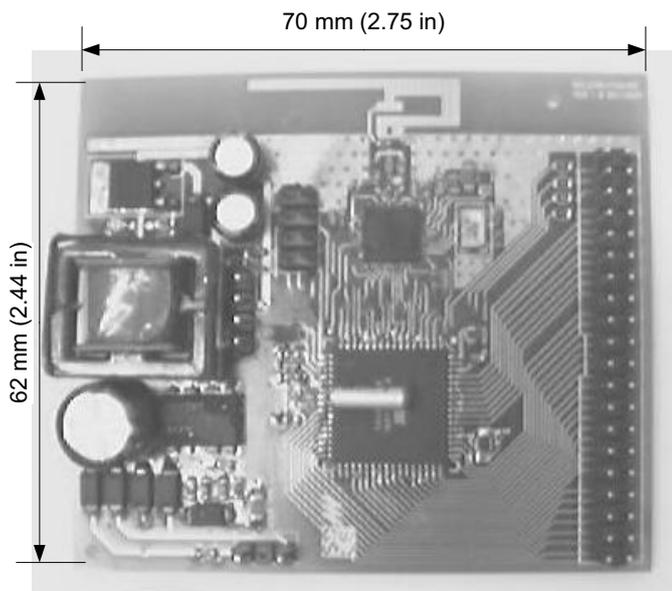


Fig. 5 IEEE 802.15.4 Node

One of those nodes was chosen to be attached to the computer and it slightly differs from others by having a RS-232 serial interface. This serial line connects the first node to the Home Sapiens control software in order to update sensors and actuators status in the graphical user interface. This node also receives and transmits the largest amount of data, but even if it goes down, the whole system would work properly since all the nodes have enough information to keep the network running. Just the graphical interface will not be refreshed. This decentralized infrastructure avoids a central point of failure and control, and the technology used is cheap enough and simple enough that it can be maintained and expanded by users with limited technology experience. Fig. 6 shows an overall diagram.

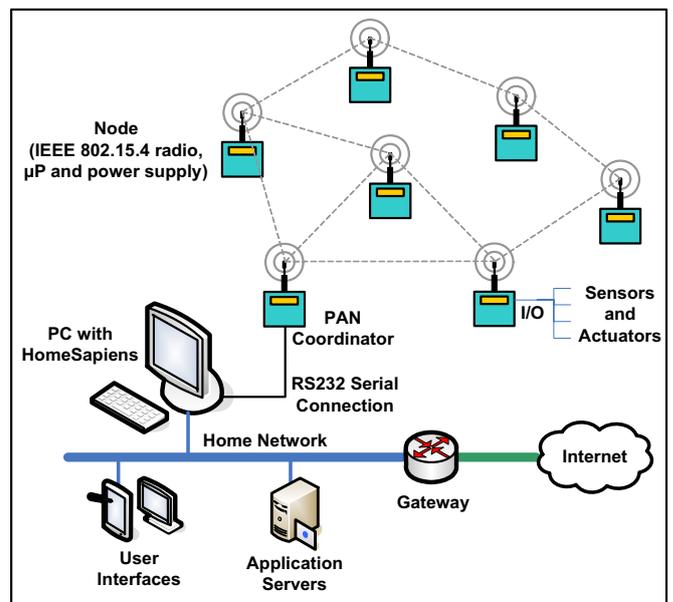


Fig. 6 Overall Diagram

The IEEE 802.15.4 radio module has an inverted-F micro strip line antenna to delivery enough power (0 to -25 dBm, software switchable) to enable smart home wireless sensor network applications.

The nodes installed were spread all over the place. The distance between the nodes was a primary concern. But in an ordinary application, i.e., inside a 400m² home, the nodes would be 30 meters away (with obstacles) from each other in the worst case. At this range, the transmission power of -5dBm was enough to transmit a data packet consuming 50mW in a 5ms window, enabling battery applications. In a home situation, there would be no need for larger ranges since the multi-routing protocol delivers the packets to any node going hop-to-hop until they reach the destination.

The job of the network is to discover the links between the nodes and to build paths so that any node can exchange data (e.g. sensor status) with any other node. Within the network, each node acts as a router and forwards packets on behalf of others. The protocol was based on a mobile mesh routing protocol and implements three specific functions: link discovery (creates a list of the neighbor nodes), identification discovery (uses logical IDs instead IEEE 802.15.4 64 bit addresses) and routing (list of each local and neighbor interface addresses which have links to it and their corresponding costs).

Although all those processes above increase the protocol overhead and the amount of control packets going from one node to another, the network becomes less vulnerable if one node goes down because the packet is re-routed to another available node. They also increase the range of the wireless network since a large, but limited, number of intermediary nodes could be added between the first node (the nearest node to the graphical interface) and the farthest node.

The maximum data rate of 250 kbps was far enough to develop smart home applications since the control frames are relatively small (maximum frame length is 131 bytes). Other

authors are already developing image transmission applications over IEEE 802.15.4 networks widening the road ahead of multimedia and data convergence process [15].

In this approach presented here, the IEEE 802.15.4 radio has a DSSS transceiver that delivers the data mapping each symbol to one out of 16 pseudo-random sequences, 32 chips each at 2 MChips/s rate. Each chip is shaped as a half-sine, transmitted alternatively in the I (in-phase) and Q (quadrature) channels with half chip period offset. The modulation format is Offset Quadrature Phase Shift Keying (O-QPSK) with half-sine chip mapping. This is equivalent to MSK (Minimum Shift Keying) modulation [16].

VI. CONCLUSIONS

Even tough interferences with Bluetooth, mobile phones and microwave ovens were not yet deeply analyzed in this work; the IEEE 802.15.4 has shown to be a very reliable and easy-to-implement wireless network in a real home scenario. The seven nodes worked right after they had been built, even on a two-layer board (the IEEE 802.15.4 radio chip producer had advised to use a five-layer board in order to reduce electromagnetic interference.)

In a 24-hour smart home application, the exposure levels of electromagnetic radiation are very low compared to limits proposed by ICNIRP (International Commission on Non-Ionizing Radiation Protection) and it is 600 times lower than an ordinary cell phone [17-19]. These radiation levels enable a very large sort of applications using low-rate, low cost wireless networks such as home monitoring, elderly people care in home environments, wearable health care systems or a personal health management service in a hospital.

The convergence of video, voice and data over IEEE 802.15.4 networks speeds up the implementation of smart homes gathering sensing information, remote command data, intercom systems and video monitoring in one simple and ubiquitous network.

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