USING SOFTWARE DEFINED RADIO AND COGNITIVE RADIO TECHNOLOGIES IN SMART HOME ENVIRONMENTS

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Abstract: The purpose of this paper is to analyse the possibility of implementing multiprotocol and multifrequency wireless Building Management Systems (BMSs) for smart home environments by using Software Defined Radio (SDR) respectively Cognitive Radio (CR) technologies. BMSs by heaving implemented these technologies or some parts of them, could provide a high level of interoperability between wireless smart home devices that could lead to a higher level of flexibility and easy implementation of current as well as future smart home standards and protocols. Starting from predefined tasks a modern smart home should fulfil, we made an analysis of SDR and CR technologies respectively intelligent building systems and finalized this analysis with conclusions regarding the possibility of using one of the best solutions to implement these technologies into BMSs.

Keywords: *software defined radio, intelligent building, cognitive radio, gateway.*

I. INTRODUCTION AND MOTIVATION

Nowadays there's a big need for intelligent building systems to reach a cost effective energy management and in the same time to provide a high level of comfort and security for smart home inhabitants.

Intelligent Building Systems (IBSs) has many subsystems as presented in figure 1, each one having its own communication network and protocol. Among smart home devices, personal electronics and multimedia devices are the most common however other devices are now also communication enabled.

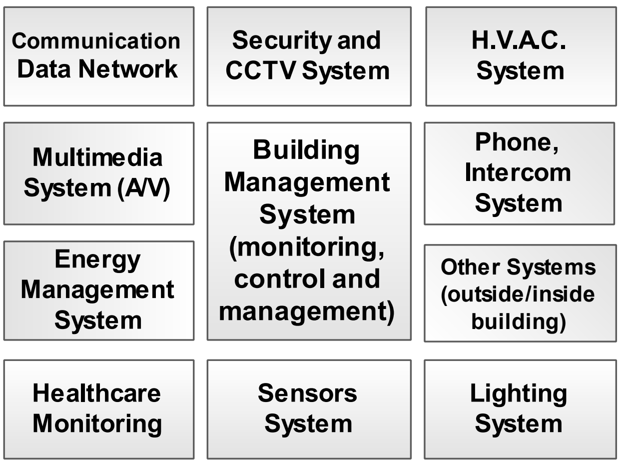

Figure 1. Smart home system.

Interoperability between these networks could open a way to enhance smart home system's capabilities (Plug and Play, easy upgrade and future extension). To have a certain level of interoperability between networks we propose a new design based on SDR, CR and Gateway technologies. Each one of these technologies will be explained in this paper but in the first step will be outlined some informations regarding IBSs.

A smart home environment has to be able to perform some kind of intelligent control, automation of different processes therefore it has to be provided with:

- communication interface,
- intelligent hardware/software to control subsystems,
- subsystem devices.

IBSs communication network can be made on "simple cable, UTP, coaxial and even fiber optical cable but the main barrier that stopped their widely usage was the high installation and maintenance costs and also that the majority of these are not suited for wide band and multimedia applications" [1] therefore we have chosen the wireless interface as base interface for our BMS core device.

"The world becomes wireless" [2], therefore more and more devices are wireless communication enabled and beside the Power Line Communication (PLC - where data transmission is made on power lines) wireless interface seem to be the best candidate for smart home devices communication interface providing a high level of flexibility.

The biggest advantage that will be provided by using the SDR and CR in BMSs is the seamless integration of any new wireless device into IBSs whatever protocol it has implemented and whatever frequency it's using as air-interface.

The rest of the paper is organized as follows: In section 2 we make an introduction to SDR and CR technologies like what does they mean, how do they

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work, in section 3 we present hardware platforms and software platforms that do exist and the chosen platforms to fulfil project requirements. In section 4 we present the proposed system, and one of the best solutions to implement SDR and CR technologies into BMSs. Section 5 finishes the paper with the most important conclusions.

II. INTRODUCTION TO SOFTWARE DEFINED RADIO AND COGNITIV RADIO TECHNOLOGIES

Currently both technologies are widely used in military and public safety areas but not in commercial or industrial applications.

2.1. Introduction to Software Defined Radio

The Software Defined Radio term was coined in 1991 by Joseph Mitola III to describe radio devices implemented in software and running on generic hardware. An SDR system is a radio communication system that:

- can tune to any frequency band, to receive any modulation across a large frequency spectrum by using software,
- perform a significant amount of signal processing in a General Purpose Processor (GPP) or reconfigurable device such as a Digital Signal Processor (DSP) and Field Programmable Gate Array (FPGA).

Tasks like modulation, demodulation, encoding and others eliminate the need for hardware components to make signal processing, the hardware will make only the basic functions like transmission/reception of signals therefore the complex signal processing will be done by processing devices.

What is SDR?

"Software Defined Radio is a radio architecture where most signal processing tasks are performed by software instead of analogue electronic circuits". [3]

Software radio seem to be one of the potential platforms for future wireless applications, this is the main reason why we try to integrate it in smart home systems. Compared to conventional wireless devices SDR it's much more flexible due to porting complex hardware functions to software that not only speeds up the development process but it creates the multi-standard support that we want to implement in smart home systems as presented in figure 2.

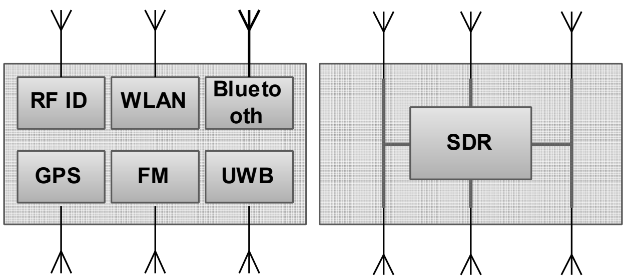

Figure 2. Conventional wireless device vs. SDR.

The particularity of SDR is the ability to change characteristics (operating parameters) such as operating frequency range, bandwidth, modulation type, data encoding, network protocol and other communication parameters by simply changing the software executed in the processing resource (GPP, DSP, FPGA) without needing different hardware modifications.

Some of advantages and disadvantages of the SDR technology are presented in Table 1.

Advantages	Disadvantages
reusability, reconfigurability (reduce time to market, maximize equipment longevity, deploy new service quickly, simplify bug fixes and software updates)	increased power consumption
multimode, multistandard, multifunction and multiband devices	large computational power is needed especially in the IF section
terminal and infrastructure versatility	more complex multi-mode operations
migration from hardware to software design	critical ADC performance such as resolution, accuracy, sampling rate, etc.
cheap technology in long term	high initial costs

Table 1: Advantages and disadvantages of SDR technology.

2.2. Introduction to Cognitive Radio

To make IBSs even more flexible an SDR based technology could be used named Cognitive Radio, term that was coined in 1998 by Joseph Mitola III. A CR is made of an SDR, some sensing hardware, sensing algorithms and some cognitive intelligence as presented in figure 3.

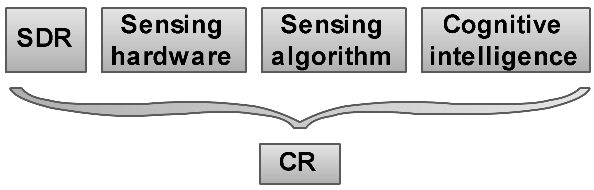

Figure 3. Cognitive Radio.

What is CR?

"An intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- highly reliable communications whenever and wherever needed,
- efficient utilization of the radio spectrum." [4].

A CR could allow devices and systems to use spectrum even more intelligently listening to determine if spectrum is being used before sending short messages and waiting for its release or finding other unused spectrum to send messages. CR would use spectrum that no-one else is using at any given time therefore its implementation into IBSs could improve communication ability of different devices.

Use of CR technology is possible only on ISM (Industrial, Scientific and Medical) bands because spectrum allocation is managed and to use a certain slice of spectrum a license is needed. This practice was introduced because of interference that occurs at a radio receiver if two or more radio transmitters are emitting radiation of the same frequency in close proximity at approximately the same power. Maybe in the future CR devices will be allowed to use very low power signals on a broad range of spectrum that will provide even more flexibility in communication between devices.

III. CHOOSE SDR HARDWARE/SOFTWARE PLATFORM

To be able to propose an SDR based system for IBSs the first step is to choose an SDR hardware having the best price/performance ratio and some software framework to control SDR hardware.

3.1. Hardware platform

There are many SDR manufacturers on the market, making different SDR experimental testbenches therefore that is not an easy task to choose one that could fulfil all the needs a certain project would require.

The most important system among commercial ones is the Joint Tactical Radio System [5] developed by the United States Department of Defense started back in 1997. JTRS is developing hardware that can reconfigure and run multiple channels of various waveforms of different protocols over a broad RF spectrum. It already incorporates more than 40 families of radios. Interoperability of this project comes from the use of Software Communication Architecture (SCA) [6].

Other important platforms that we have analyzed are:

- WARP. Rice university wireless open-access research platform, [7]
- Universal Software Radio Peripheral (USRP and USRP2), developed by Ettus Research LLC, [8]
- Lyrtech's Small-Form-Factor SDR - Development Platform, [9]
- Anywave®Base Station, developed by Vanu®, Inc., [10]
- Kansas University Agile Radio (KUAR) developed by University of Kansas, [11]
- High Performance SDR [12].
- CalRadio [13].

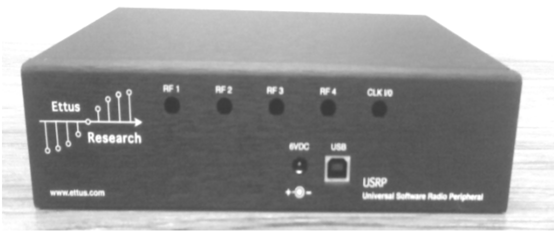

Figure 4. USRP platform.

After analyzing parameters of all these hardware platforms we have chosen the USRP platform (figure 4) because it fulfilled all requirements that our project has outlined:

- It has a small form factor,
- It has a small power consumption,
- Common external interface: USB,
- Wide operating frequency band to support many air-interfaces,
- Moderate cost to be implemented into BMS device,
- High manufacturing yield,
- Reconfigurable baseband with processing resources to implement many waveform types,
- Modular SDR platform, expandable with various RF front-ends having different parameters.

Technical details:

The USRP module is made of a motherboard and several daughterboards. The motherboard has the following characteristics:

- 4 x ADC (12bit, 64MSPS),
- 4 x DAC (14bit, 128MSPS),
- FPGA for pre-processing tasks,
- USB 2.0 interface to host PC (32 MB/s),
- 4 Digital Down Converters (DDC), implemented in FPGA with Cascaded Integrator-Comb (CIC) filters,
- 4 Digital Up Converters (DUC),
- Capability to process up to 16MHz wide signals – up to 8MHz spectral bandwidth due to Nyquist criteria,
- Able to transfer 8 mega complex samples/sec across the USB,
- RSSI (Receive Signal Strength Indicator) to sense signal level - can be used to implement a part of the cognitive radio, to sense if there’s any signal on a given RF band. There are 3 possibilities to measure it: Analog RSSI, Digital RSSI in FPGA or Digital RSSI in host computer,
- 2 RX and 2 TX ports,
- Adjustable transmit power,
- FPGA firmware update through USB port.

To be able to control devices working on different ISM bands a WBX daughterboard had been chosen that has the following characteristics:

- It’s a transceiver that has a full-duplex type communication,
- Frequency: 50 MHz – 2.2 GHz,
- Tx power : 50 - 100 mW (17-20 dBm) for frequency below 1 GHz and 30 – 50 mW for frequency above 1 GHz,
- Noise figure: 5 - 6 db,
- Sensitivity: better than -130 dBm (for whole range of frequencies),
- AGC Range: 70 dB,
- IIP2: 40 - 45 dBm,
- IIP3: 5 – 10 dBm.

The antenna that will receive and transmit RF signals is a Log Periodic type antenna made by Kent Electronics, that has the following characteristics:

- Frequency: 400 MHz – 1 GHz, with a maximum of 1150 MHz,
- Gain: varies a bit with frequency but it’s in the range of 5-6dBi,

- Very directional, ideal for point-to-point link,
- VSWR: 2:1 transmitter and 3:1 receiver, suited for transmitters up to 10W,
- Ideal for wireless LAN's and other wireless devices.

Due to USRP's capabilities described before it can be used for many applications like:
- Software GPS,
- Distributed wireless sensor networks,
- Distributed measurement of spectrum utilization,
- Ad-hoc mesh networks,
- RFID reader,
- Digital Audio Broadcasting (DAB) transmitter,
- and many more.

We have chosen USRP instead of other SDR devices because:
- it's ease of use, it's less tied to the hardware compared to other devices,
- flexibility provided by the FPGA and ease of programming by the PC,
- it has the best price/performance ratio.

3.2. Software platform

Development environments for SDRs cover a wide range of softwares. An SDR environment is based on object-oriented technologies that are used to create functional components that are connected together to process waveforms.

As well as in the case of hardware platforms there are many software platforms, each one having its own advantages and disadvantages.

Available software platforms:
- Software Communication Architecture (SCA) - is an open-architecture framework that specifies how the software and hardware will work together,
- GNU Radio [14] - is an open source software development toolkit that enables runtime signal processing; it has a layered structure where the top layer application programs are written in Python script language while the bottom layer contains computational intensive signal processing blocks written in C++ language. These blocks represent the functionality of complex communication blocks implemented in conventional hardware devices,
- OSSIE, SCARI – both are SCA-based open source SDR core frameworks,
- LabView, Matlab/Simulink – USRP module is flexible enough to be used with these solutions by using different drivers to access data from SDR hardware,
- And many other programs like ROCKY [15], WINRAD [16], SDRADIO [16], Flex-Radio PowerSDR [17], all of these used for testing purpose not for developing.

The best software framework that we chose to be integrated into BMS's software is the GNU Radio, because there's a possibility to emulate Python environment and run scripts directly from BMS software not having to deal with low level C++ programming. Scripts that describe protocol and air-interface parameters will be provided when a new device will be installed into IBS.

IV. IMPLEMENT SDR INTO BMSs

There are too many smart home protocols and standards developed by different companies, each one having their own advantages and disadvantages so there would be a good solution to have a highly reconfigurable control unit to be able to control different devices whatever protocol or standard having implemented.

To implement the SDR and CR technologies into a BMS device there are two possibilities:
- Mobile device (preferably Smart phones, Pocket PCs, Tablet PCs and other wireless communication enabled mobile devices),
- Gateway device.

4.1. Implementation into handheld device

One possibility would be to implement these technologies (USRP device) in a mobile device as presented in [18], but this has many disadvantages:
- has a big size for a mobile device,
- short battery life,
- antenna size (Log Periodic antenna is too big to be used with mobile devices).

Many researches are made in this direction, to reduce energy consumption and size respectively to use Multiple Input Multiple Output (MIMO) antenna arrays to be integrated in mobile devices like Smart phones.

4.2. Implementation into Gateway device

One of the best solutions that could bring many advantages to BMSs would be the implementation of SDR technology intro Gateway devices.

A Gateway device has the ability to connect the inside world with the outside world as it's presented in figure 5. This concept is not a new one, but it can be extended by implementing new technologies like SDR and CR to improve it.

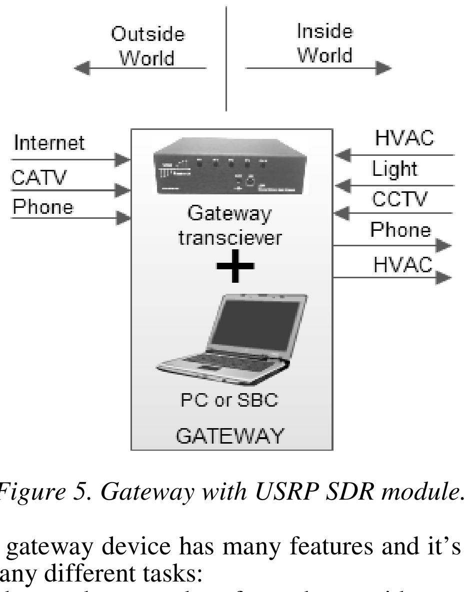

Figure 5. Gateway with USRP SDR module.

The gateway device has many features and it's able to fulfil many different tasks:
- can be used to get data from the outside world like CATV or phone and to distribute signals through the whole building,
- can help different devices working on various air-interfaces and protocols to interact between them,

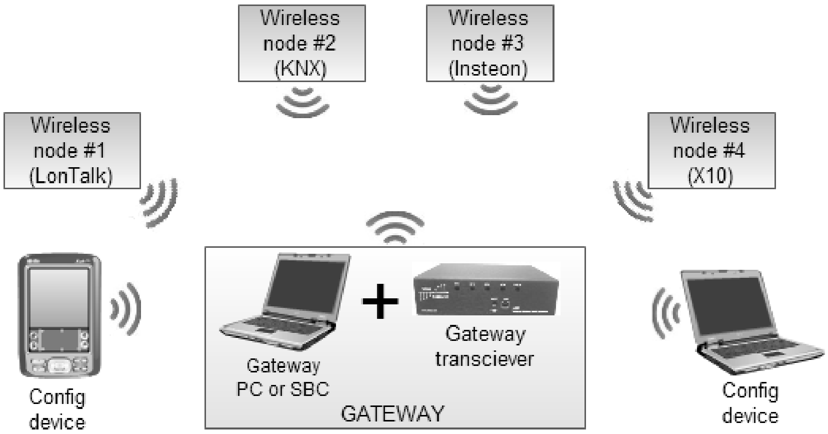

Figure 6. Intelligent Building System based on gateway device.

- can be used to monitor various parameters from a building by monitoring wireless sensors working on different protocols,
- can be used as an intermediate device between control/monitoring devices (PDAs, Smart phones, Table PCs, PCs, etc.) and other devices being part of the BMS by hiding the complexity of the network and in the same time providing a very simple, user friendly interface for users.

To have a more compact device with smaller power consumption there is possible to use a Single Board Computer (SBC) instead of a PC. The configuration of new devices will be made with control/monitoring devices as presented in figure 6.

The gateway device made with USRP SDR will be the BMS core device, a true management system therefore it needs some database to store data related to new devices added to the system, to store monitored data for future analysis, and other data.

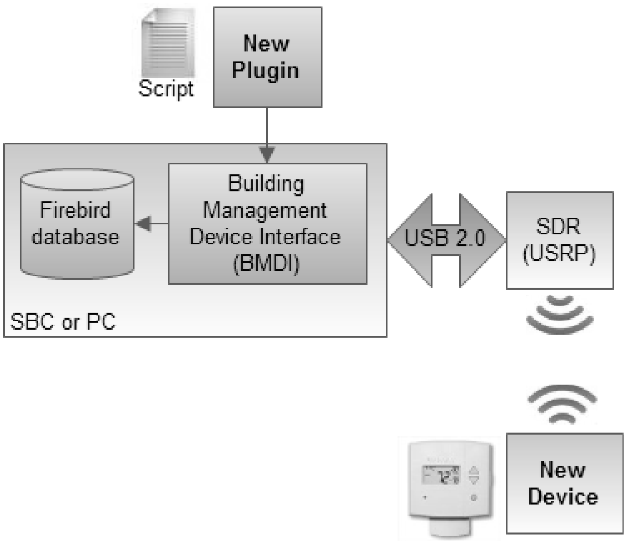

Figure 7. System configuration (new device + script).

The database management system we have chosen is the Firebird RDBMS because it's a very robust and exceptionally reliable relational database therefore its usage will bring many advantages to BMS core device.

The BMS will be a plug-in based system that will introduce an easy way to extend an IBS by setting devices parameters through a script (frequency, modulation, timings, implemented protocol and many other parameters) therefore new devices will be attached easily to IBSs as presented in figure 7.

Each system has limitations, like this one, too. The most noticeable limitation is the bandwidth that is only 8MHz. To solve this problem the USRP2 could be used that has 25MHz bandwidth and Ethernet connection for data transfer to processing device.

Anyway in the initial development of this system the gateway device will be used to manage devices attached to it, will control and monitor devices (mainly sensors) therefore data transfer rate will be low (around 10 Kb/s, that will work with X10 and Insteon devices; Insteon devices are working on sub GHz frequencies like 915 MHz, 900 MHz, etc.).

As mentioned before, to make the IBS even more flexible, there is possible to make an RF to PLC interface, to convert RF packets and send them on power lines to different devices. This would be very helpful to develop the lightning subsystem and other subsystems where the majority of control signals are ON/OFF commands.

As described in [19] an intelligent building should be "flexible and adaptable to deal with change", this is what we have proposed in this paper with the SDR based gateway device, to make a very flexible and adaptable IBS that can be extended very easily in old and new buildings due to its wireless interface.

As described in [1] "Nowadays there are few technologies, with wide recognition, wide range of products but having nothing in common with each other so the adoption of a global communication protocol is impossible", anyway the usage of the SDR technology will enable the BMS core device to work with various devices on different protocols. Protocols that could be used are: X10, Profibus, Insteon, BACnet, LonTalk (LonWorks), EIB and many others by simply describing through a script the protocol, modulation, air-interface, etc. it has implemented.

The main idea behind the implementation of SDR and

CR technologies into Gateway devices is to make a BMS that will be able to manage devices working on different protocols, in this way future IBSs will not be bound anymore to devices having implemented a certain protocol (like BACnet, LonTalk, etc.), but they will be able to choose any device having implemented any protocol that will be integrated into the IBS through the BMS by installing the plug-in containing the scripts and other information related to that device.

The whole flexibility of IBS and BMS is provided by SDR capability to process signals by software (with GPP and DSP – using FPGA reconfigurability in baseband) not by the hardware as in conventional wireless devices.

V. CONCLUSION

The research conducted to establish optimal system implementation of SDR and CR technologies has been completed with conclusions regarding their implementation into gateway devices instead of mobile handheld devices allowing interoperability between different devices working on various protocols and frequencies. The presented theoretical approach and the proposed system could be very useful in today's and future IBSs by providing a high level of flexibility and allowing a seamless integration of any new device into IBSs by using the SDR technology's advantages.

There are many improvements that can be made to this system, like the implementation of the cognitive radio technology that could help to make a true Plug and Play system giving IBSs more value, but that is a very complex task and can be mentioned as a future development.

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