Evaluation of Software Defined Radio Systems for Smart Home Environments
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Abstract – Software Defined Radio systems are predicted to be radio access networks of next generation in all kind of wireless communications systems. Their use is not limited to radio front end that is first chosen for system operation. They can be upgraded by time as system needs changes or evolves which gives them radio front end flexibility never seen before in radio systems. Smart home environments such as eWALL system and other uses numerous of wireless technologies to control lot of appliances in them or to monitor specific health state of the people living there etc. Therefore, lot of wireless technologies have been developed solely for that purpose, leaders among them are ZigBee and Z-Wave technologies which are today standard for wireless home automation systems that are energy efficient and secure. Software Defined Radio is certainly very useful for future mobile communication systems. In this work Software Defined Radio system will be evaluated with a purpose of introducing local radio networks that are used in smart home environments based of Software Defined Radios. Benefits and shortcomings of using Software Defined Radio in this systems will be shown and evaluated.

Keywords – Software Defined Radio, smart home environments, local area networks, ambient assisted living, smart living, ubiquitous computing

1. INTRODUCTION

Software Defined Radio (SDR) is enabling technology for future wireless communication systems. Software Defined Radios are used today primary for research purposes but devices that will have the same or similar functionalities as Software Defined Radios will be used for future wireless communication systems. Re-configurability and re-programmability are key aspect of this kind of wireless communication systems. All technical systems that are made to be reconfigurable and reprogrammable are showing good perspective in future high-tech systems, such as Field Programmable Gate Array (FPGA) devices that are also key components of modern Software Defined Radio architecture.

Ambient assisted living is a wide term because it implies many research fields such as:

- Smart home environments
- Ambient intelligence
- Context aware computing
- Multi agent systems
- Robotics
- Internet of Things
- Wireless Sensor Networks
- Artificial Intelligence
- Human to Computer Interaction

As it is related to many research areas Ambient assisted living is also related to social economic trends in European countries. European union is community of different member states but its laws and economic practices in field of healthcare can still vary from state to state. There is a same challenge in development of AAL system both on technological and socio-economic level. This trend can also be seen in field of assisted living for elderly people. For example elderly people from Sweden often go to elderly residence in the south of Spain where residence for elderly people is cheaper and weather is warm. There is more than 5000 nursing homes in Spain and they are mostly private owned. For people who are staying in Sweden when they are in elderly age there are senior housing facilities which can be adapted to senior wishes regarding domotics, health care support and Ambient assisted living in general. Denmark is known for do-it-yourself retirement community because there groups of friends or like-minded people develop their own villages or apartments for living at elderly age. In every country pension schemes are different in amount of money that seniors receive per month as well in amount in healthcare support and other benefits in general for seniors that can be state financed. Technological trends in Ambient assisted living must conform to newest trends from medicine, economy, law and psychology. Developing of Ambient assisted living system that will be useful, affordable and admissible in all the EU is therefore complex task [1]. eWALL is Ambient assisted living system that is being developed by consortium financed by EU FP-7 research program. Architecture of eWALL system is shown on Figure 1.
T3.1: Sensor design/selection & interfacing
Signal processing
T3.2: In/out-house networking
Sensor streams
T3.3: Non-A/V perception
T3.4: A/V perception
T3.5: Indexing in home database
Sensors
Digital Analog sensors
Microcontroller/
Microcontroller Platform (Arduino)
Radio Module
XBee
The Sensor part
The Local Gateway
Platform/PC
Radio Module
XBee
Figure 1 Architecture of eWALL - ICT system for AAL living.

Continua Health Alliance [2] announced that lifestyle management can address 60-80% of all cases, that happen to senior citizens, of unpredictable cases in the wellness and pre-illness conditions. It is obvious that the costs for the seniors and the National Departments of Health thus can be significantly reduced with introduction of AAL systems to environments in which elderly people spent most of their time. Large number of researchers and initiatives are trying to cope with the task of introducing AAL systems to everyday life of elderly people.

2. SENSOR TO GATEWAY WIRELESS CONNECTION IN SMART HOME/AAL ENVIRONMENT

Sensors are very important for AAL systems because they are producing low level metadata that is used later in AAL system for smart and intelligent reasoning. Metadata that is coming from these sensors need to be measured and transmitted safely to central gateway in AAL or smart home environment. Hardware and system level connection between sensors in smart home or AAL environment to central home gateway is given in Figure 2 and Figure 3.

Connection between sensors, actuators and home gateway [3] can be done on wireless or wired way. Wireless connectivity offers freedom of nodes positioning all around the smart home/AAL space of interest but can be problematical when wireless connected sensor or actuator is on the edge where wireless signal can reach. Nevertheless this method of connecting sensors or actuators in this kind of environments is more usual than wired connections. Power Line Communications are becoming more and more represented for networking of various devices in smart home as well as in AAL environments. This market is rapidly growing because technology, primary chipsets, that enables this kind of communication are becoming more accessible and affordable. Most notable alliance of companies in field of Power Line Communications is Home Plug Alliance and CSEP – consortium for SEP2 interoperability. Vision of Home Plug Alliance connected home is shown on Figure 4.

Figure 2 Possible hardware setup of sensor to gateway connection in smart home or AAL environment.

Figure 3 Sensors to gateway connection in smart home or AAL environment from system level perspective.

Figure 4 Home Plug Alliance vision of connected home environment.

Home Plug Alliance is committed to providing standards and set of guidelines for devices that are used for Power Line Communications. Home Plug Alliance defines Home Plug AV standard that is used to deliver an energy efficient and cost effective networking with optimized throughput for applications such as devices automation/control in smart home environment, security monitoring, energy management, device automation and all other machine to machine communications that are tolerant to communication latency. Most important standards regarding this leading Power Line Communication group are IEEE 1901 and IEEE 1905.1 standards. IEEE 1901 standard describes PHY and MAC specifications for power communication devices...
across the entire spectrum of In-Home, Transport and Smart Grid applications. IEEE 1905.1 standard describes how to make benefit from using wide adopted standards including Wi-Fi (IEEE 802.11), Ethernet (IEEE 802.3), HomePlug AV (IEEE 1901) and MoCA (coaxial cables) in a software abstraction layer. With this standard it is shown how combination of wireless and wired networks can be beneficial for high performance in house networking. IEEE 1905.1 basically combines performance and reliability of wired networks with the flexibility of wireless for mobile devices. Data rates that can be offered by today’s Power Line Communication devices can go up to 1 Gbps. This data rate is sufficient to support modern multimedia services in whole smart living/AAL space of interest.

CSEP, consortium for SEP2 interoperability is very interesting because it combines both wireless standards such as ZigBee, WiFi, Bluetooth and Home Plug Alliance to make devices that will conform to IEEE 2030.5 standard. This standard defines applications that enables home energy management via wired and wireless devices that support IP.

Wireless connection is still the most used way of connecting sensors and actuators in smart home/AAL environments. Most used wireless protocols for connection with sensors and actuators are:

- Bluetooth
- WiFi
- Z-wave
- ZigBee

Some technologies such as Bluetooth Low Energy and ZigBee have found special place in smart home/ambient assisted living environments because they are part of Continua Health Alliance. Continua Health Alliance is an international non-profit organization with mission to offer end-to-end, plug-and-play connectivity of devices and services for personal healthcare. ZigBee Alliance in document [4] defines ZigBee profile for wireless networks that are used to implement wireless communication in healthcare systems. Uses cases for ZigBee networks that are dedicated for healthcare applications are divided into next categories:

1. Disease management (DM)
   - Non-critical patient monitoring (episodic)
   - Non-critical patient monitoring (continuous)
   - Patient alarm monitoring (low acuity)
   - Drug administration (e.g. insulin pumps)
2. Personal Fitness Monitoring (PFM)
   - Monitoring / tracking fitness level
   - Personalized fitness schedule
3. Personal Wellness Monitoring (PWM)
   - Activity monitoring
   - Safety Monitoring
   - Living independently

It can be seen that this applications domain suits perfectly to case studies in smart home and ambient assisted living environments that are defined by Continua Alliance.

### Table 1 ZigBee, Bluetooth and Bluetooth LE technology comparison.

<table>
<thead>
<tr>
<th></th>
<th>ZigBee</th>
<th>Bluetooth</th>
<th>Bluetooth LE</th>
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<tbody>
<tr>
<td>Network architecture</td>
<td>Multiple</td>
<td>Point-to-point</td>
<td>Point-to-point</td>
</tr>
<tr>
<td>Devices supported in network</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Frequency band</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>MAC/PHY specification</td>
<td>IEEE 802.15.4</td>
<td>IEEE 802.15.3</td>
<td>IEEE 802.15.1</td>
</tr>
<tr>
<td>Latency</td>
<td>&lt;0.5 ms</td>
<td>10 ms</td>
<td>&lt;0.5 ms</td>
</tr>
<tr>
<td>Battery life</td>
<td>&lt;10 years</td>
<td>Days</td>
<td>Weeks</td>
</tr>
<tr>
<td>Data rate</td>
<td>250 Kbit/sec</td>
<td>1-3 Mbit/sec</td>
<td>1 Mbit/sec</td>
</tr>
<tr>
<td>RF Range</td>
<td>&lt;50 m indoor</td>
<td>10 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Security</td>
<td>128 bit AES</td>
<td>128 bit AES</td>
<td>128 bit AES</td>
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### 3. SOFTWARE DEFINED RADIO ARCHITECTURE AND ITS POSSIBLE APPLICATIONS IN SMART HOME/AAL ENVIRONMENT

Software Defined Radio is wide term that can describe various reconfigurable radio systems. Software Defined Radio system is often associated with term cognitive radio that is just one, but most widespread, field of research around Software Defined Radio architecture and its applications. Software Defined Radio concept was introduced in 1999 by Joseph Mitola [5]. In this work Joseph Mitola explained the vision about reconfigurable and software components in radio front end communication chain. Goal was to make framework for reconfigurable wireless architecture so one radio device can work within multiple wireless communication systems. Most used Software Defined Radio system today is Universal Software Radio Peripheral (USRP) system firstly build by company Ettus Research which was then acquired by National Instrument. System design of USRP Software Defined Radio system is given on Figure 5.

![Figure 5 Architecture of NI USRP Software Defined Radio system.](image)

One of the key characteristics of USRP platform is radio frequency signal down and up conversion before ADC/DAC converters and Field Programmable Gate Array (FPGA) platform behind converters in radio front end chain. Field Programmable Gate Array (FPGA) platform is used for down converting sampled digital IF signal to digital baseband signal. After digital down conversion the signal is passed through digital filters and then sent to PC via USB 2.0 connection for further data demodulation. Similar thing is happening in transmit direction with difference of performing digital up conversion to digital IF signal instead of down conversion.

Front-end Daughter cards of USRP platform are used for implementation of radio front end circuits from antenna to the digital part of SDR system. The cards are offered in wide radio frequency bands from 10 MHz to 6 GHz so they can be
used for emulation of almost any radio frequency wireless communication system that is used today. There are numerous of projects conducted by university research groups and technological companies in which SDR USRP platform is used for emulation of modern high end wireless base station systems such as LTE, GSM, IEEE 802.11, IEEE 802.15.4, etc. All projects are implementing base stations using USRP platform in combination with PC. It is shown that all the issues that arise in this kind of wireless communication system implementation can be solved by modifying hardware or the software part of the system. Most of the systems are programmed using GNU Radio framework for USRP Software Defined Radio programming. One device can theoretically be used for implementation of different radio communication protocols with just change of the software. There are also applications of Software Defined Radio systems that are used for purposes such as radio astronomy [6].

Architectures of smart home environments, especially ambient assisted living environments rely on complex ontologies that define ambient assisted living environment architecture from data models point of view [7]. Ontologies aim to add semantics, i.e. meaning, to information to allow for reasoning over the data to derive further knowledge. Further reasoning in smart home environment can be implemented on a central home computer [8] and can also include ontologies for deployed sensor networks. In the past few years there has been work in order to define ontologies for sensors and sensor networks. As a result a number of ontologies have been defined that serve different purposes, applications and domains. Ontology that is developed by W3C consortium for sensor networks can be seen in Figure 6. This field of research is especially important for addressing future Internet of Things systems that will deliver a lot of data from different sensor sources in near future.

Software Defined Radio can be used as a wireless hub in smart home/ambient assisted living environments to support unification of wireless links used in environment of that kind through one device. One Software Defined Radio system device can be used to control various wireless controlled domotic systems as well as other wireless multimedia systems that are used in environment. Wireless controlled domotic systems are usually not working full time so their reduced duty cycle is ideal for using one Software Defined Radio system device to control lot of wireless devices that can be supporting different wireless protocols on different frequencies made by different electronic equipment manufacturers.

4. CONCLUSION

In this work concept of smart home environments and ambient assisted living environments was presented through various methods and technologies that are used for wireless and wired connectivity in them. This connectivity is used for different purposes from controlling of home automation systems to streaming of multimedia data to user devices such as smartphones or tablets. Key aspects of current standards and technologies in this field is shown and concept of Software Defined Radio system as a general purpose wireless hub for controlling all wireless related device in smart home/ambient assisted living environment is given. In future work concept of controlling devices that utilize different wireless communication protocols with one Software Defined Radio will be implemented using National Instruments USRP radio platform.

REFERENCES

[4] ZigBee Health Care Profile Specification, ZigBee Document 075360r15, ZigBee Alliance March 2010