HUMAN PRESENCE DETECTION USING RADIO IRREGULARITY IN WIRELESS NETWORKS
Human Detection in Energy Aware Residential Networks

Bojan Mrazovac[1], Milan Z. Bjelica[1], Dragan Kukolj[1], Branislav M. Todorović[2] and Saša Vukosavljev[2]
[1]*Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovica 6, 21000, Novi Sad, Serbia*
[2]*RT-RK Institute for Computer Based Systems LLC, Narodnog Fronta 23a, Novi Sad, Serbia*

Keywords: Energy awareness, Domotics, RSSI, Radio irregularity, Smart outlets, Wireless sensor networks, Zigbee.

Abstract: The paper presents a human detection method applied to the intelligent device-level software platform for residential energy management. The proposed solution increases user awareness and automates the power control, with the primary goal to contribute in energy savings. Instead of using conventional presence sensors as inputs for automated power management, the proposed solution utilizes a network of wireless power outlets and monitors the variations of the signal strength indicator used for the communication between them. The radio signals used for the inter-outlets communication can be scattered, absorbed or reflected by objects in their propagation paths, such as a human body which additionally increases the variation of the signal strength indicator at the receiver. This phenomenon is known as radio irregularity, and is often considered as a shortcoming of radio networks. In this paper the idea of using radio irregularity as efficient presence detection is proposed. With regard to conventional sensors, this solution preserves the pervasiveness of smart energy and smart home systems, high level of sensorial intelligence and low installation costs.

1 INTRODUCTION

Weiser's dream has already begun (Weiser, 1999). Our homes became temples of various integrated services and intelligent devices that provide us with necessary information, communication and entertainment. With the capabilities built into today's gadgets to adapt their behaviour to a consumer's habits and manners, the possibilities are unlimited. The complex infrastructure of smart devices follows the trend to become ubiquitous, seamlessly woven into the fabric of everyday life.

More complex infrastructure requires more energy to be consumed. The required energy sources have become exhausted and the solution to preserve them is to increase user awareness. In order to decrease the energy wasting, several solutions have been already proposed. The most popular power saving solutions are based on wireless smart outlets (Song et al., 2008). By using smart outlets and web-based power management services, consumers are able to monitor the power consumption of each plugged device and to perform a simple set of commands (Weiss and Guinard, 2010). It is possible to display the consumption of each appliance in conjunction with the costs for a specific time period, to switch it off or on and to protect from so called "Vampire power loss" on standby outlets (Han et al., 2009).

Even the consumers, which have insight into the consumption data, usually forget to take small corrective actions to improve the efficiency. The main issue we indicate in existing systems is that the energy management is based on a user's instruction, without the possibility for the system to adapt automatically. For instance, the system should be able to turn off or dim the lights in a room if no people are present for a period of time. To enable the system to react automatically, it is needed to establish the interaction with the environment. This interaction involves a number of sensors, used mainly for human detection, that help creation of a smart home ecosystem. Conventional sensors for human and motion detection (passive infrared, 3D camera, ultrasonic…) require additional costs and installation procedures, complex data processing algorithms and mostly, burdensome wiring interfaces (Mrazovac et al., 2011). Technologies that

Mrazovac B., Z. Bjelica M., Kukolj D., M. Todorović B. and Vukosavljev S..
HUMAN PRESENCE DETECTION USING RADIO IRREGULARITY IN WIRELESS NETWORKS - Human Detection in Energy Aware Residential Networks.
DOI: 10.5220/0003803700050014
In *Proceedings of the 1st International Conference on Sensor Networks* (SENSORNETS-2012), pages 5-14
ISBN: 978-989-8565-01-3

would affect humans in the future should become transparent in the environment, ubiquitous and always prepared to interact. By following such trends, wireless sensor networks (WSN) are considered as good solutions. However, instead of using conventional wireless sensors for presence detection, another approach would be to use the impact of a person's presence on wireless signals nearby.

Some novel localization techniques analyze the received signal strength indicator (RSSI). It is the most applicable solution for WSN due to the low deployment costs and easy integration into wireless systems. In this paper, the method for indoor human detection applied to the smart energy residential wireless network is proposed. The method utilizes wireless nodes which are part of pre-existing home electrical installations (smart power outlets and light switches) and communication signals nearby. In this research the nodes have two roles: (a) control of the plugged devices as well as of giving an overview on energy consumption; (b) human presence detection enabled by the analysis of the radio irregularities between radio transceivers embedded in wireless nodes. Since human body interferes with the radio signal, irregularities in radio signatures can be used as an indication of human presence within a room. Presented processing algorithm for human detection is of negligible complexity compared to the conventional sensors. The proposed method increases user awareness by enabling a certain level of sensorial intelligence for automated operations with the primary goal to achieve the energy savings. To the best of our knowledge, there are no available residential smart energy systems that are able to monitor the consumption and, at the same time, to detect human presence by analyzing and quantifying the irregularities in radio signals used for communication.

In the following section the method of using RSSI variations for indoor human presence detection is presented. The method extends an existing smart energy infrastructure with the level of intelligence for automated operations. Detailed measurements of RSSI variations in different environments confirm the usability of the proposed solution. At the end of the paper a conclusion with the idea for the future improvements is given. Experimental results show the amount of saved energy achieved by using the presented energy ecosystem combined with the proposed human presence detection method.

2 DETECTION METHOD USING RADIO IRREGULARITY

In this section the phenomenon of radio irregularity, its causes and impact on signal propagation in wireless networks are defined. In the subsection 2.1 the related work on the radio irregularity and the relevance of such approach for human activity and motion detection are shown. In the subsection 2.2 the method for indoor human presence detection is proposed. The method is used as an integral part of the energy aware ecosystem.

2.1 General Analysis of Radio Irregularity – Related Work

Radio irregularity is a common phenomenon in wireless networks. It arises from multiple factors, such as different signal radiated powers caused by hardware calibration and different path losses in different directions of transmitted signal. Zhou, He, Krishnamurthy and Stankovic (2004) set a number of experiments which show that radio irregularity is mainly caused by two factors: device properties and the propagation medium. Device properties include the antenna gain and type, the transmitter's radiated power, the receiver's sensitivity and threshold and signal-to-noise ratio (SNR). Medium properties include the background noise and the environmental factors like obstacles within the propagation media.

One of the major causes of radio irregularity is the variation in the signal path loss. When the signal travels through a medium, it may be scattered, reflected or diffracted. Scattering occurs when the signal propagates through a medium which contains a large number of objects smaller than the signal's wavelength. Reflection occurs when the signal, during its propagation through a medium, encounters an object which is larger than the signal's wavelength. Diffraction occurs when the signal encounters an irregular surface, such as sharp edges.

The signal path loss can be also affected with hardware imperfections of transceivers. It is possible that a transceiver does not have the same antenna gain in all directions. The power supply (battery) status change also leads to variations in signal transmitting power by resulting in different signal strengths at the receiver's input.

Signal strength variations in indoor environments due to the radio irregularity are even more expressed when a human body encounters the signal in its propagation path. The human body is comprised of skeleton, flesh and body liquids which are able to additionally absorb, scatter or reflect the radio signal. Since human bodies interfere with the radio signal, the presence of a subject in the wireless network results in larger signal strength fluctuations at the receiver input. One of the earliest researches (Woyach et al., 2006) reports that the shadowing effect caused by human subject moving in the line-of-sight path between transmitter and receiver can be used for human detection. This approach, mainly based on RSSI variations monitoring at the receiver, is extended for outdoor people counting mechanism (Puccinelli et al., 2011). By analyzing the radio irregularity phenomenon in WSN, Lee et al., (2010) investigated the feasibility of intrusion detection based on the signal strength fluctuations. They succeeded to characterize the signal strength fluctuations and translate them into sufficient information that corresponds to a human activity. The idea of using RSSI fluctuations is applied on an indoor automated people counting mechanism (Lin et al., 2011).

It is important to mention that a human body in the aforementioned researches neither transmit nor receive any form of wireless signal unlike the researches presented by Ahn and Yu (2009) and Chen et al., (2008) and references therein. These researches present the techniques of localizing unknown nodes positions and tracking of mobile wireless devices within a wireless sensors network. The presented techniques are also "supported" with the radio irregularity and the variations of the RSSI between network nodes.

2.2 Presence Detection Method

The primary focus of this method is presence detection, which means that a subject may be static within the sensing area. The proposed solution allows the system to be always aware of human presence or motion even if a person sits or sleeps inside a room, making the environment more comfortable for living. Presence detection method is mainly based on utilizing the shadowing effects between stationary wireless nodes which line-of-sight is obstructed by a human body.

RSSI often fluctuates in different environments with higher or smaller variations around the mean value. Experimental analysis presented in section 4 confirms that the RSSI variation over a period of time is even more expressed when a person is present. In an empty room, the initial RSSI variation defines the interval of initial signal strength variation (ISSV). This interval is set during the system initialization when wireless nodes communicate with each other by exchanging the messages and values of RSSI for each communication link, making the "radio image" of the environment. During the initial phase, the sensing area is empty and the RSSI is only obstructed by the environmental and devices properties. Signal strength variation in initial conditions is used to define the high and the low bounds (thresholds) of ISSV. The ISSV bounds are calculated based on a set of RSSI samples taken for a minute. This time interval is not strictly defined; it is chosen to be one minute because of a round number of samples obtained from nodes during the interval. The number of nodes in this research is 4 and the polling time of each node is 100ms. After the set of one minute samples is formed, the standard deviation and the expression given in (1), which calculates the ISSV bounds, are executed. ISSV bounds algorithm is based on a comparison of the differences between the mean value ($\bar{x}$) of the set and the set's min and max values ($x_{min/max}$).

$$ISSV_{high/low} = (|x_{\min/\max} - \bar{x}| / x_{\min/\max}) \cdot 100 \qquad (1)$$

The comparison of the mean value against the min/max values defines ISSV bounds whereas standard deviation is the additional control factor. These three elements together define the detection condition. Within the ISSV, RSSI can vary without recognized detection. When a human enters the sensing area the RSSI starts to vary greatly by exceeding the ISSV bounds and deviating from control factors, which results in detected presence. Two bounds are used, because the signal's nature is such that it can vary below and above its mean value. The signal deviation can vary significantly across different environments, making the definition of universal bounds difficult. That is the main argument why the bounds definition is necessary during the initial phase. Bounds are also recalculated periodically for the case of room layout change (positioning the furniture). The one minute sliding window of RSSI samples periodically calculates the standard deviation based on the received samples. During the initial phase, the signal deviation is very small. When a subject enters the room and obstructs one of the propagation paths the RSSI deviation on that radio link is increased. After the subject exits the room, the recalculated signal deviation value is restored to the initial. If the subject changes the furniture layout before leaving a room, the new layout also increases signal deviation. The additional software mechanism monitors the signal deviation over period of environment changes (PEC). If the signal deviation is constant during the PEC interval, regardless of the initial value, the system detects room layout change and new ISSV bounds are recalculated based on the last minute of samples.

Realization of the system includes at least two wireless nodes (outlets or in combination with light switches). The communication control and the ISSV analysis are implemented in the associated control unit (*Home Controller - HC*) which is made in the form of an embedded PC. These basic system units communicate with each other and monitor the ISSV. At the same time, these components provide the automated energy management. As the final result the system controls e.g. lighting in a room, but in addition to the lighting control, the system can be preconfigured to control any other device which is connected to the smart outlets.

The contribution of the presented solution is the reduction of a number of physical devices and the elimination of additional sensors (presence sensors and RFID tags). To the best of our knowledge, this is the first RSSI variation monitoring algorithm applied solely to the smart power outlets extended to detect human presence. Experimental confirmation of the proposed presence detection method extends the related researches mentioned in section 2.1 which analyse the techniques for motion detection.

3 THE SMART ENERGY RESIDENTIAL ECOSYSTEM

The proposed method for human detection is applied to the smart energy residential ecosystem. The smart energy ecosystem consists of a home controller device and a number or smart power outlets and light switches mounted in existing home electrical installations. The system analyzes RSSI fluctuations between wireless nodes (outlets and light switches) conditioned by human entering or leaving a room (as illustrated on Figure 1).

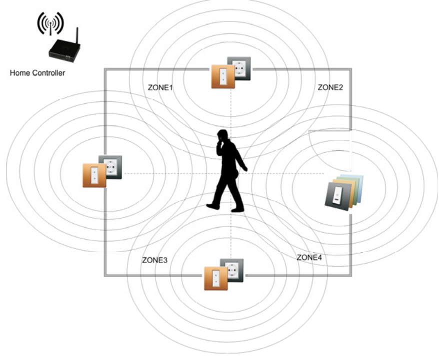

Figure 1: Presence detection in smart energy ecosystem.

3.1 The Home Controller

The home controller (illustrated in Figure 2) presents a software platform based on open standards (POSIX/C) which provide scalability. The controller is platform independent, and currently it can be easily installed on both Windows and Linux OS platforms. The design of the platform's modules ensures that new devices (additional outlets or switches) can be added seamlessly, without re-architecture of the platform's design.

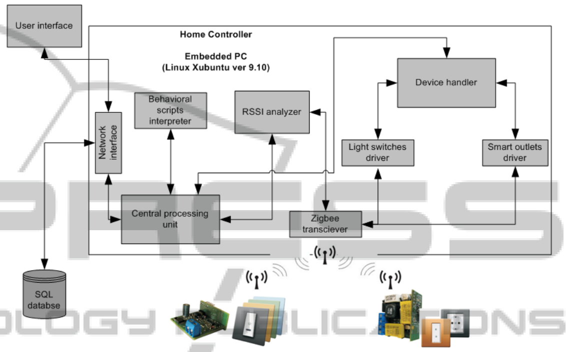

Figure 2: The Home Controller design overview.

The device handler is connected to device drivers units providing a communication mechanism with the nodes. This module is in charge of sending the control messages as the responses on detection events. The RSSI analyzer module performs periodic polling of outlets and light switches to retrieve the current values of RSSI. The RSSI analyzer has access to the list of nodes' addresses, polls them in turn on every 100ms and saves the received values in the local storage database.

After a node receives the polling command from the controller it sends its RSSI table as broadcast message. The message contains a table of RSSI values toward all links (other nodes) within a room. During the period of one node polling the other nodes are in the "listening" mode, so there is no interference or superposition between them. The broadcast message is received on the controller side as well as by other nodes which then update their RSSI tables with the values of signal strength from that link. The nodes are able to receive the message from the home controller as well as from other nodes. After the message is received, the RSSI analyzer saves the received samples into the local database and waits for the next 100ms, to poll another node. The procedure is repeated until all nodes send their RSSI values toward all links. After the RSSI table is completed, the processing module calculates standard deviation and ISSV bounds.

After the bounds are defined, the polling procedure is repeated for obtaining new samples which are compared with the predefined bounds. If the samples exceed the ISSV, the presence is detected.

The concept of behavioural patterns, explained in details by Bjelica et al., (2011), enables the energy ecosystem to be used for various setups of an environment. Behavioural patterns are presented in the form of XML (*Extensible Markup Language*) scripts which define timely actions and respond to external events, such as human detections, with the primary goal to achieve desired energy consumption scheme. The scripting language is similar to high-level programming languages by having a support for declaration and usage of variables, loops, if-then-else constructs, delays and sleep instruction and the commands for control of smart outlets and light switches. The script interpreter module (shown as a block in Figure 2) executes the script and interprets the behaviour. Mrazovac et al., (2011) described the design of the smart energy residential ecosystem which is used as the power management platform, including its comparison with commercially available solutions for smart power metering such as *Plogg*, *Plugwise* and *digitalStrom*. The proposed algorithm for presence detection can be integrated into various wireless power outlets and other similar solutions, by extending their metering purpose with the detection capability.

The home controller software runs on a PC based on CPU Intel Atom Z530 1.6GHz with 2GB DDR2 RAM under Linux OS. The communication protocol is ZigBee (IEEE 802.15.4) which is established by using CC2531 USB dongle.

3.2 Smart Outlets and Light Switches

Smart outlets and smart light switches, presented by Mrazovac et al., (2011), fit into existing electrical installations, standard sockets on the wall. Smart outlet provides power to electrical devices with standard flat, two-pole AC power plug, called Europlug (CEE 7/16) which is designed for voltages up to 250V and currents up to 2.5A. Besides simple on/off switching it is able to pass any percentage of power to the consuming electric devices (e.g. a light dimmer). TI CC2530 ZigBee RF transceiver (2.4GHz) is used as the communication module. It has an RSSI status register which value represents the signal strength in 8bit basis. Smart outlets are powered from 220-240Vac (±10%) 50Hz current electric power supply. It is the cheapest and the safest way which provides full compatibility with the regulatory requirements. With an average current of 35mA and operational voltage of 3.3V for an outlet and 2.4V for a switch, the power consumption is around 0.12W per outlet and 0.08W per switch.

4 EXPERIMENTAL RESULTS

In this section the analysis of RSSI variations caused by a human presence in two different environments is presented. The mean value, the standard deviation and ISSV bounds calculated for a testing time period are presented. The system described in section 3 has been installed in two buildings whose walls were made of different materials: (a) gypsum with fibreglass isolation, (b) aluminium with plastic covers and fibreglass isolation. The RSSI variations in such environments and processing results are shown in the following subsections. Four nodes have been used for each experiment, three outlets and one light switch, which is often room situation.

4.1 Gypsum Wall

The first set of tests was performed in a building which walls were made of gypsum attached to the construction elements (steel) and isolated with fibreglass. The wall thickness was 15 cm. The layout of a testing room is shown on Figure 3. Red points illustrate the nodes positions, blue the subject's positions and yellow point with green spot illustrates the central (x=0, y=0) position. Nodes were placed at an elevation of 40 cm (switch was at 1.20cm) above the floor.

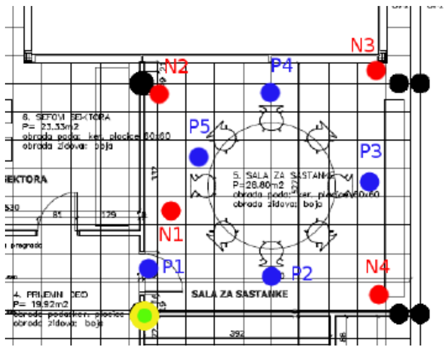

Figure 3: Room with gypsum walls isolated with fibreglass.

The room dimensions were 536×530cm. The distance (in cm) of each node from the central position is shown in the first two columns of Table 1. The last two columns show the positions of a subject within the room.

Table 1: Nodes' and subjects positions – gypsum walls environment.

Node name	Distance (cm)	Position name	Distance (cm)
N1	(73, 211)	P1	(0, 78)
N2	(54, 477)	P2	(270, 75)
N3	(474, 428)	P3	(424, 254)
N4	(519, 66)	P4	(306, 420)
-	-	P5	(120, 255)

The test scenario was the following: the room was empty for a period of two minutes, and no detection was reported. Once a subject entered the room, he performed walking within the room by passing the positions P shown in the Figure 3. After one minute of walking, the subject was standing in each position P for one minute without movements. The scenario tried to confirm the hypothesis that is possible to distinguish motion, presence or an empty room. The raw samples of RSSI variations retrieved from each node are shown in Figure 4.

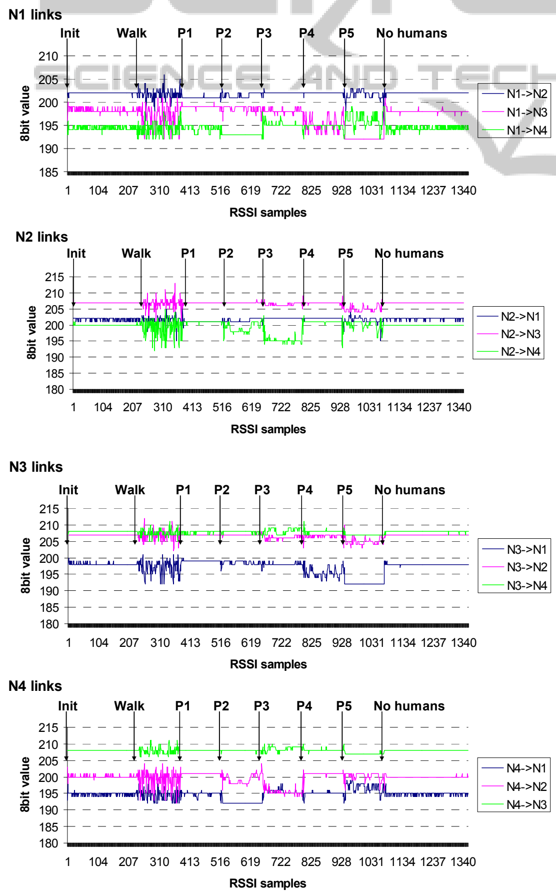

Figure 4: Experimental results for gypsum walls.

From the Figure 4 it can be observed that in the position P1 the RSSI variation was the highest for the link N1→N4 in both directions. It is explained as a result of signal reflection by the human body which was very close to the line-of-sight between outlets N1 and N4. In the position P2, the human body shadowed the links N1→N4 and N4→N1, so the most of the radio signal was absorbed by the human body which was the main reason for lower RSSI values. In the position P2, the links N2→N4 and N4→N2 were distorted with the reflection by the human body, so the high RSSI variation in the position P2 for links between outlets N2 and N4 can be noticed. The position P2 had slight influence on the links N1→N3 and N3→N1, which were also distorted by the vicinity of human body which slightly reflected the signal. The human position P3 mostly absorbed the signal from the links N2→N4 and N4→N2, and also reflected the signals from the links N3→N4, N4→N3 and N1→N4, N4→N1. Position P4 shadowed the links N1→N3 and N3→N1 and absorbed the signal. The position P5 also shadowed the links N1→N3 and N3→N1 and reflected the signals from the rest of links, except for N3→N4 and N4→N3 which were far from the human. At the end of the experiment the room was empty again for two minutes.

In the Table 2, the standard deviation (*Std. Deviation*), the mean value (*Mean value*) and the ISSV bounds calculated by (1), are shown. Calculations are performed over a set of initial two-minute samples retrieved during the time when the room was empty.

Table 2: Initial state - gypsum walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	201.99	0.11	0.49	0.01
N1→N3	198.22	0.48	1.13	0.89
N1→N4	194.38	0.52	0.72	0.82
N2→N1	201.74	0.44	0.37	0.13
N2→N3	207	0.07	0	0.48
N2→N4	200.03	0.16	0.01	0.48
N3→N1	198.10	0.31	0.05	0.95
N3→N2	207	0	0	0
N3→N4	208	0.07	0.48	0
N4→N1	194.75	0.4	0.91	1.64
N4→N2	200.13	0.41	1.07	1.41
N4→N3	208	0	0	0

The Table 3 shows ISSV bounds and the signal strength deviation when the human was standing in the position P1. The calculations are performed over a set of one minute samples.

Position P1 was very close to nodes N1 and N4, so the RSSI variation for this link in both directions was the highest, because of the body which reflected the signal, resulting in a higher standard deviation. ISSV bounds also show the highest values for these two links. Comparing with the initial measurements it can be seen that these values exceed the initial ISSV bounds and the signal strength deviation. It is enough that the values exceed the ISSV interval at only one link and the presence would be reported.

Table 3: Position P1 – gypsum walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	201.05	0.09	0	0.49
N1→N3	198.95	0.13	0.5	0.53
N1→N4	194.29	0.78	1.19	0.36
N2→N1	201	0	0	0
N2→N3	206.99	0.09	0.28	0
N2→N4	200.98	0.13	0.49	0.01
N3→N1	199	0	0	0
N3→N2	207	0	0	0
N3→N4	207.82	0.18	0.4	0.08
N4→N1	194.82	0.59	0.94	0.63
N4→N2	201	0	0	0
N4→N3	208	0	0	0

The position P2 (shown in Table 4) is in the line-of-sight between nodes N1 and N4, so the most of the signal was absorbed by the human body, and also no high deviations were observed. But reflection by the body detected on the links N2→N4 and N4→N2 has reported detection.

Table 4: Position P2 - gypsum walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	201.47	0.5	0.24	0.26
N1→N3	198.66	0.55	1.36	0.17
N1→N4	193	0	0	0
N2→N1	201.4	0.49	0.2	0.3
N2→N3	207.02	0.12	0.01	0.47
N2→N4	199.09	1.28	1.06	0.95
N3→N1	198.6	0.49	0.3	0.2
N3→N2	207.02	0.12	0.01	0.47
N3→N4	207.91	0.28	0.44	0.04
N4→N1	192.01	0.09	0	0.51
N4→N2	199.13	1.25	1.6	1.42
N4→N3	207.98	0.12	0.48	0.01

Because the paper size is limited, it is not possible to show the rest of the results for all the positions, but the conclusion is the same: RSSI for all nodes that communicate far from the human's position vary slightly or has a constant value. When a human is close to a node, but not in the line-of-sight, the RSSI varies greatly because of the signal reflection which is shown to be the most powerful radio irregularity feature that can report presence in this environment. When a human shadows the line-of-sight, the RSSI deviation is very low, and the signal strength does not exceed the ISSV. But, the other links which line-of-sight is near are distorted with the reflection. It is enough that RSSI exceeds the ISSV only on one link and the detection would be reported.

4.2 Aluminium Wall with Combination of Plastic

The second set of measurements was performed in a building which walls were made of aluminium and plastic slices with fibreglass isolation. The room dimensions were 960×580 cm and the wall thickness was 30 cm. Red points illustrate the nodes positions, blue the subject's positions and yellow point with green spot illustrates the central position. The room layout is shown in Figure 5.

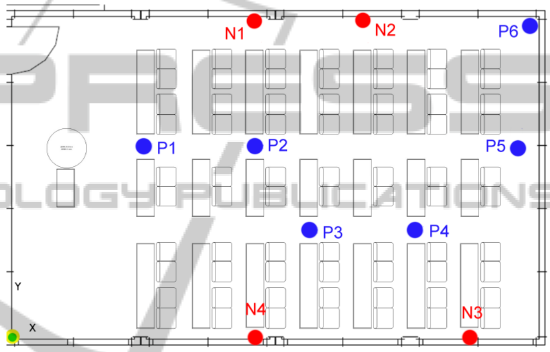

Figure 5: Room with aluminium and plastic walls.

The distance (in cm) of each node from the central position is shown in the first two columns of Table 5. The last two columns show the positions of a subject within the room.

Table 5: Nodes' and subjects positions – alu/plastic walls environment.

Node name	Distance (cm)	Position name	Distance (cm)
N1	(410,530)	P1	(220,305))
N2	(600,530)	P2	(410,305)
N3	(795,40)	P3	(500,150)
N4	(410,40)	P4	(690,150)
-	-	P5	(945,305)
-	-	P6	(955, 500)

This environment is interesting because of the wall structure, which forms a Faraday's cage so the signal is strongly reflected by the walls. From the initial measurements shown on Figure 6 it can be noticed that the signal strength varies even in an empty room, so the initial values for *Min var* and *Max var*, including signal strength deviation are higher than the initial values in previous building.

The test scenario was slightly different from the scenario explained in the previous subsection. The room was empty for a period of two minutes, and no detection was reported. Once a subject entered the room, he was standing in each position P from Figure 5 for one minute without movements. After samples from all P positions were collected, the subject performed one minute walking within the room by passing the positions P. The raw samples of RSSI variations retrieved from each node in this environment are shown in Figure 6.

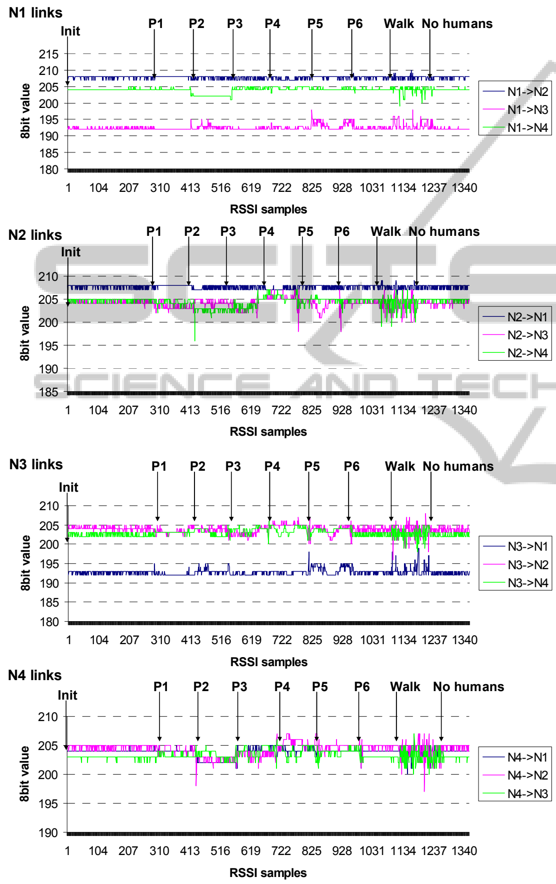

Figure 6: Experimental results for alu/plastic walls.

From the Figure 6 it can be observed that in the position P1 the RSSI variation was low or similar to the initial state (empty room) for all the links. This is explained as a result of strong signal reflection by the walls combined with the human body which was close to the N1 and N4. In the position P2, the human body shadowed the links N1→N4 and N4→N1, so the most of the radio signal was absorbed by the human body which was the main reason for lower RSSI values. The position P2 had slight influence on the links N1→N3, N3→N1, N2→N4 and N4→N2, which were distorted by the vicinity of human body which slightly reflected the signal. The human position P3 reflected the signal from the links between nodes N2 and N4 and also reflected the signals from links N2→N3, and N3→N4 in both directions. Position P4 strongly reflected the signals on links between nodes N2 and N4, and also N3 and N4. The position P4 slightly absorbed the signals between nodes N2 and N3. The position P5 showed RSSI variations on links between nodes N1 and N3, which is the most probably because of the signal reflection by the wall and human body which were close to each other. The strongest impact on the signal strength in the position P5 was noticed for the links between nodes N2 and N3. The position P5 reflected the signal, and together with the wall reflection increased the RSSI variation. The position P6 which was the furthest position from all nodes, showed very low signal strength variations. The system did not detect a subject standing in the position P6 - "blind position". Since the room was large, during the nodes positioning installers did not keep in mind to cover all "blind positions". So for larger rooms the installers should consider installing more outlets for better radio coverage, which is usually the case for larger rooms. Otherwise, the system will report false detections. At the end of the experiment the subject was walking around the room, trying to move closer to nodes N2, N3 and N4, and radio links therein, without obstructing the line-of-sight between nodes N1 and N2. After the one minute of walking, the room was empty.

From the Figure 6 it can be observed that the wall reflection and reflection by the human body mostly affected signals in this environment. The Table 6 shows the measurement results for the initial state. Tables 7 shows the measurement results for the position P5 which mostly interfered with the radio signals in this environment. The table 8 shows the results in position P6 which is the furthest position from all wireless nodes.

Table 6: Initial state – alu/plastic walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	207.86	0.35	0.41	0.07
N1→N3	192.22	0.41	0.11	0.40
N1→N4	204.03	0.16	0.01	0.47
N2→N1	207.78	0.41	0.38	0.11
N2→N3	204.26	0.45	0.62	0.36
N2→N4	204.82	0.39	0.4	0.09
N3→N1	192.74	0.46	0.38	1.16
N3→N2	204.06	0.53	1.02	0.46
N3→N4	202.47	0.51	0.23	0.75
N4→N1	204.01	0.08	0	0.48
N4→N2	204.81	0.39	0.40	0.09
N4→N3	202.96	0.2	0.47	0.02

Table 7: Position P5 – alu/plastic walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	207.87	0.34	0.42	0.06
N1→N3	193.04	1.16	0.54	2.5
N1→N4	204.08	0.28	0.04	0.45
N2→N1	207.64	0.48	0.31	0.17
N2→N3	203.74	1.35	2.9	1.57
N2→N4	204.88	0.51	1.42	0.55
N3→N1	193.31	1.07	0.68	0.87
N3→N2	203.68	1.29	1.84	1.6
N3→N4	203.5	0.63	1.25	0.73
N4→N1	204.12	0.38	0.55	0.43
N4→N2	204.84	0.74	1.41	1.04
N4→N3	203.71	0.78	1.35	0.63

Table 8: Position P6 – alu/plastic walls.

Link	Mean value	Std. Deviation	Min var [%]	Max var [%]
N1→N2	207.86	0.35	0.42	0.07
N1→N3	192.26	0.44	0.14	0.38
N1→N4	204.07	0.26	0.03	0.45
N2→N1	207.79	0.41	0.38	0.1
N2→N3	204.25	0.43	0.12	0.37
N2→N4	204.86	0.35	0.42	0.07
N3→N1	192.77	0.42	0.4	0.12
N3→N2	203.84	0.67	0.41	0.56
N3→N4	202.46	0.50	0.23	0.27
N4→N1	204.02	0.23	0.5	0.48
N4→N2	204.84	0.52	1.41	0.56
N4→N3	202.96	0.18	0.48	0.02

The results in this room are different from those in the first building. The reflection by the human body interfered with the walls reflection mostly affected the radio signals. But even in such environment, the presence and motion detection can be easily recognised.

5 POWER MANAGEMENT EXPERIMENT

The presented human detection method implemented for residential smart energy management was analyzed in the experiment of controlling 7 bulbs of 100 Watts. The regular control included the worst case when a user leaves the light on, after leaving a room. The presented system for energy consumption control switched off the light automatically after 5 seconds if no humans were detected within a room.

In the Figure 7 the achieved power savings in the testing house (110m²) applied to the lighting control are shown. The test has been performed during one working day with four-member family (two adults and two kids). The house contained three bedrooms, one kitchen and dining room, one bathroom, one foyer and one living room. Test subjects performed normal behaviour at home, trying to manually save the electric energy by switching off the lights in all empty rooms (shown as a blue line in Figure 7). In each room one lamp was plugged to a smart power outlet and one to a standard power outlet. Smart power outlets with plugged lamps were under automatic switch control, whereas standard power outlets were under users' manual control. Supported with the proposed presence detection algorithm the energy consumption used for lights was lower from 1260 Watts to 780 Watts at the end of the day.

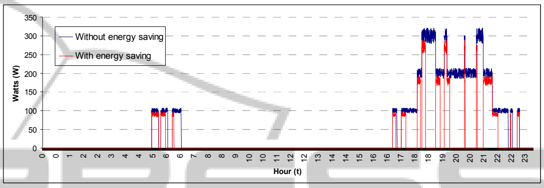

Figure 7: The energy saving experiment supported with the proposed presence detection method.

6 CONCLUSIONS

In this paper the novel method for human detection applied to an energy aware residential network is presented. The method utilizes radio irregularity phenomenon to detect human presence. To the best of our knowledge this is the first paper presenting the human presence detection achieved by using a network of smart power outlets and light switches within a room. The presented analysis confirms the hypothesis that the presence detection is possible by monitoring the radio signal variations between wireless power outlets. The proposed solution defines the RSSI variations bounds during the system initialization and periodically if the static signal deviation is noticed. When a human enters the sensing area, RSSI values exceed the interval's thresholds resulting in reported detection. It can be concluded that for larger rooms, the level of false detections increases. It is shown that some positions in a large room were out of the detection scope. For that case the detection accuracy was 86%. For the standard room dimensions, the detection accuracy was 100%. Correct detection requires good radio coverage within a room which depends on the nodes' positions. As the future improvement the authors will try to replace the ISSV definition algorithm with another metric which will recognize a presence in the system by using a single parameter. The benefit of such an approach would facilitate the installation of a larger number of additional smart outlets without changing the core of the processing algorithm. The energy savings achieved by using the smart energy ecosystem supported with the proposed detection method are significant. Authors believe that this idea will encourage other manufacturers to apply the presented approach to their smart meters and help the global awareness for energy saving.

ACKNOWLEDGEMENTS

This work was partially supported by the Ministry of Education and Science of the Republic of Serbia under the Grant projects TR-36029, TR-32034 and TR-32041, year 2011.

REFERENCES

Weiser, M., (1999). The Computer for the 21st Century. *ACM SIGMOBILE Mobile Computing and Communications*, Vol. 3, No. 3, 3–11.

Song, G., Ding, F., Zhang, W. and Song, A., (2008). A wireless power outlet system for smart homes. *IEEE Trans. on Consumer Electronics*, Vol. 54, No. 4, 1688-1691

Weiss, M. and Guinard, D., (2010). Increasing Energy Awareness Through Webenabled Power Outlets. *Proc. of 9th ACM Inter. Conf. on Mobile and Ubiquitous Multimedia*, doi:10.1145/ 1899475.1899495

Han, J., Lee, H. and Park, K. R., (2009). Remote-Controllable and Energy-Saving Room Architecture based on ZigBee Communication. *IEEE Trans. on Consumer Electronics*, Vol. 55, No. 1, 264-268.

Mrazovac, B., Bjelica, M. Z., Papp, I., Teslic, N., (2011). Smart Audio/Video Playback Control Based on Presence Detection and User Localization in Home Environment. *Proc. of 2nd Conference on the Engineering of Computer Based Systems (ECBS-EERC '11)*, doi: 10.1109/ECBS-EERC.2011.16

Zhou, G., He, T., Krishnamurthy, S. and Stankovic, J. A., (2004). Impact of radio irregularity on wireless sensor networks. *In proc. Of MobiSys '04*, doi:10.1145/ 990064.990081

Woyach, K., Puccinelli, D. and Haenggi, M., (2006). Sensorless sensing in wireless networks: Implementation and measurements. *In proc. Of the 2nd International Workshop on Wireless Network Measurement (WiNMee)*, 1-8

Puccinelli, D., Foerster, A., Puiatti, A. and Giordano, S., (2011). Radio-based trail usage monitoring with low-end motes. *In proc. Of the 7th IEEE International Workshop on Sensor Networks and Systems for Pervasive Computing (PerSeNS)*, 196-201

Lee, P. W., Seah, W. K. G., Tan, H.-P., Yao, Z., (2010). Wireless Sensing Without Sensors – An Experimental Study of Motion/Intrusion Detection using RF Irregularity. *Measurement Science and Technology*, Vol. 21, No. 12, doi:10.1088/0957-0233/21/12/124007

Lin, W.-C., Seah, W. K. G., Li, W., (2011). Exploiting Radio Irregularity in the Internet of Things for Automated People Counting. *Accepted by the 22nd Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*

Ahn, H.-S. and Yu, W., (2009). Indoor Localization Techniques based on Wireless Sensor Networks. *Mobile Robots - State of the Art in Land, Sea, Air, and Collaborative Missions*, 277-302.

Chen, C.-C., Wang, D.-C. and Huang, Y.-M., (2008). A Novel Method for Unstable-signal Sensor Localization in Smart Home Environments. *International Journal of Smart Home*, Vol. 2, No. 3, 55-72

Bjelica, M. Z., Mrazovac, B., Teslic, N., (2011). Evaluation of the Available Scripting Languages for Home Automation Networks: Real World Case Study. *Proc. of 10th Intern. Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services (TELSIKS'11)*.

Mrazovac, B., Bjelica, M. Z., Papp, I., Teslic, N., (2011). Towards Ubiquitous Smart Outlets for Safety and Energetic Efficiency of Home Electric Appliances. *Proc. of Intern. Conference on Consumer Electronics (ICCE '11)*, doi: 10.1109/ICCE-Berlin.2011.6031795.