UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
Más que un estado sólido
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRONICA
A CASE-STUDY VISION

Energy saving system with wireless sleep sensor

Sistema de ahorro energético con sensor inalámbrico de sueño

Camilo Andrés Cerquera-Salinas[1], William Fernando Rodríguez-Sarmiento[2], Luis Fernando Pedraza-Martínez[3]

INFORMACIÓN DEL ARTICULO

Historia del articulo
Envíado: 12/12/2018
Recibido: 13/12/2019
Aceptado: 10/02/2019

Palabras clave:
Z-Wave,
estado de sueño,
sensor,
domótica,
ahorro energético,
frecuencia respiratoria.

Keywords:
Z-Wave,
sleep state,
sensor,
Domotic,
energy saving,
respiratory rate.

RESUMEN

En el siguiente artículo se realiza el desarrollo y evaluación de un dispositivo capaz de identificar el estado de sueño de una persona a partir de la medición de la frecuencia respiratoria, integrándolo a un sistema tipo Z-Wave para realizar control domótico espacial. Se evidenció, por medio del análisis de pruebas de consumo eléctrico, cómo la implementación del sistema genera un ahorro significativo del 38% con respecto al consumo promedio mensual en una vivienda, y cómo su aplicación contribuye con un entorno propicio para dormir al disminuir el ruido que generan los equipos multimedia en la habitación -apagados inmediatamente después de una detección-. Se observa un correcto funcionamiento del sensor por las características de las mediciones de los parámetros de calidad de servicio (QoS): Delay, Throughput y Jitter, garantizándose que la pérdida de información es nula y que el sistema implementado es viable.

ABSTRACT:

In the following paper, perform the development and evaluation of a device capable of identifying the sleep state of a person from the measurement of the respiratory frequency, integrating it into a Z-Wave system to perform spatial domotic control. It was evidenced, by means of the analysis of electrical consumption tests, how the implementation of the system generates a significant saving of 38% with respect to the average monthly consumption in a house, and how its application contributes to an environment conducive to sleep by reducing noise that generate the multimedia equipment in the room -off immediately after a detection-. The correct functioning of the sensor is observed due to the characteristics of the measurements of quality of service (QoS) parameters: Delay, Throughput and Jitter, guaranteeing that the loss of information is null and that the system implemented is viable.

1BSc. In Telecommunications Engineering, Electronic Technologist, Universidad Distrital Francisco José de Caldas, Colombia. Labor Technician in Systems, Institute Ingabo, Current position: OSC Telecoms & Security Solutions, Documenter Consulting. Email: camilo.cerquera@osctelecoms.com.co ORCID: https://orcid.org/0000-0003-4926-9257

2BSc. In Telecommunications engineering, Electronic Technologist, Universidad Distrital Francisco José de Caldas, Colombia. Technologist in Design and integration of Mechatronics automatisms, SENA, Colombia. Current position: Ecospace Soluciones Inteligentes SAS, Automation Engineer. Email: williamrodriguez@ecospace.design ORCID: https://orcid.org/0000-0001-5972-6170

3Ph.D in Engineering, Universidad Nacional de Colombia, Colombia. Current position: Professor at Universidad Distrital Francisco José de Caldas, Colombia. Email: lfpedrazam@udistrital.edu.co ORCID: https://orcid.org/0000-0002-0997-6478

Cite this article as: C. A. Cerquera-Salinas, W. F. Rodríguez-Sarmiento and L. F. Pedraza-Martínez "Energy saving system with wireless sleep sensor", Visión electrónica, vol. 2, no. 1, Special edition, january-june 2019 https://doi.org/10.14483/issn.2248-4728

1 Introduction

In recent years there has been a demographic growth associated with the increase in the quality of life and a progressive industrialization, which is proportional to the increase in electricity consumption that generates higher greenhouse emissions with negative repercussions for the environment [1][2] . For this reason, it is necessary to opt for clean energy, boost savings and energy efficiency.

In the previous perspective, one of the mechanisms to reduce electricity consumption is to analyze the time lapses in which people waste energy, since a considerable expense is found in the hours of sleep where no electrical or electronic device should work, unless it's vital.

In particular, systems dedicated to energy efficiency in the home have been designed taking advantage of technological advances and different communication technologies for domotic control. Within these are the protocols used for residential wireless automation. Specifically, one is designed by the company Zensys - based on interoperable communications technology, wireless, radio frequency- designed for control applications, monitoring and reading of residential environments known as Z-wave,[3] .

This low power radio frequency communications technology supports full mesh networks without the need of a coordinating node; it operates in the sub-1GHz band, being impervious to Wi-Fi interference and other wireless technologies in the 2.4 GHz range (Bluetooth, ZigBee, etc.). The protocol is designed for control and status applications with data speeds of up to 100 kbps, encryption AES128, IPV6 and multi-channel operation. The Z-Wave physical access and media layers (PHY / MAC) have been ratified by the International Telecommunication Union (ITU) as the international standard (G.9959),–. In addition, it allows total interoperability through layer 6 with compatibility for all versions,[3].

Regarding the use of the Z-wave protocol in applications related to domotic control, there are intelligent control systems with wireless transmission with mobile devices for electronic block control ; remote control of devices within a wireless LAN network [6]; biological signal monitoring systems such as respiration and the vital signs,[8].
On the other hand, concerning to the monitoring and detection of sleep states, different technologies and alternatives may be available. Among these are the provision of biological sensors in sleep monitoring applications; as well as the analysis of incident factors in the measurement environment and the applications of systems with wireless communication protocol. It is also used in the detection of movement by precision of sound using sound waves with automatic system based on a sensor of ZigBee technology, [9]; including the provision of mattresses for the non-invasive detection and without restrictions of bio-signals,[10].
On the other hand, Electrocardiographic telemetry systems (T-ECG) based on Z-Wave and heart rate measurement have been developed, [11][12].

Likewise, and through infrared depth sensors, RGB cameras and microphones, the distinction of alterations in sleep has been achieved, [13]. In this same way, sleep detectors have been designed taking into account electrooculography and electroencephalography ; an individual's sleep cycle detectors, and environmental temperature adequacy to maximize sleep efficiency using the fast Fourier transform applied to heart rate signals, [15] .

Now, with regard to the detection of sleep positioning, it is found that by exploring the use of wireless measurements with Intensity of the received signal (RSS), a person can be detected as well as their location in the home.[16]; likewise, discrete approaches for the detection of states and positions of sleep have been documented [17] and indoor location methods using Zigbee [18]. Finally, algorithms for real-time sleep analysis have been developed and studies for the quantification of it by means of signal measurement,[20].

According to the analysis of the aforementioned, the present investigation intends to design a device capable of detecting the sleep state of a person and integrate it into a domotic system of Z-wave technology that guarantees energy efficiency. To identify the sleep state, the sleep characteristics mentioned in the Harvard medical school are taken into account, where it is indicated how the breathing patterns change during sleep, as well as the respiratory frequency decreases slightly becoming regularized, [21].

The article is structured in the following way: Initially a contextualization is made about Z-wave and the technologies that have been used for the measurement of sleep status; Subsequently, aspects related to the materials and the methodology used in the development of the prototype are addressed; followed by this the process of performance testing and quality of service is described. In the next section, the results are analyzed; and finally, conclusions and future works of the research carried out are provided.

2. Materials and methods

Based on the previous text and the review of the project background, the methodology is proposed for the development of this project shown in Figure 1.

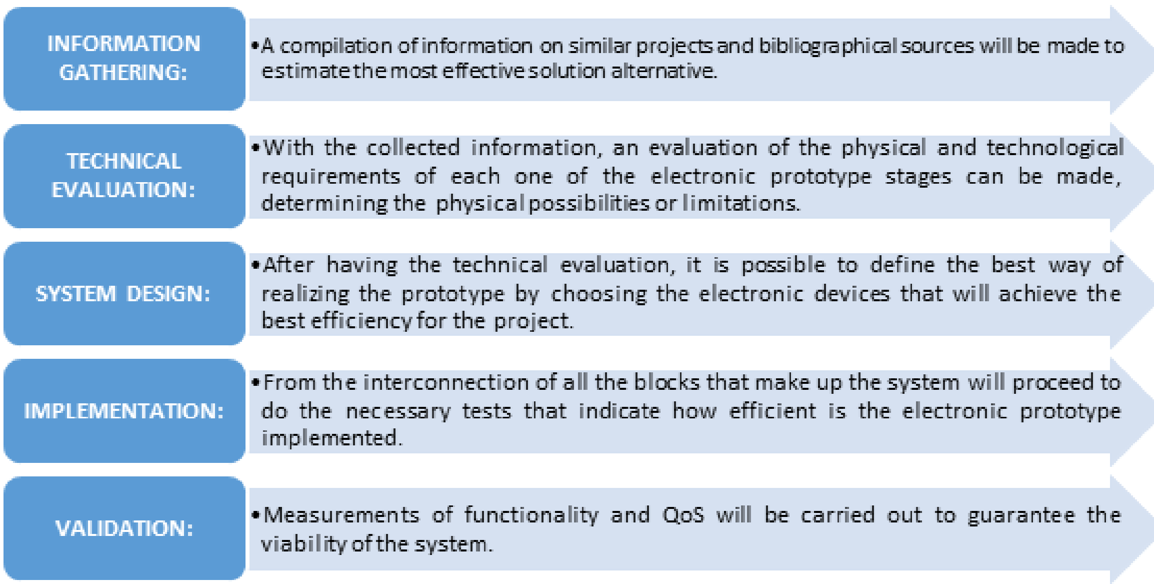

Figure 1. Methodology. Source: own.

The process of design and implementation of the system that will allow the detection of sleep without breaking into the ergonomics and comfort of each person, is proposed as a non-invasive type that uses the sound of breathing to identify the dream state. The system is integrated into a Domotic system with Z-wave technology to be used as a sensor with which different devices connected to the network can be controlled. These, at time, must be dedicated to generating energy savings. To do this, the prototype is designed shown in Figure 2.

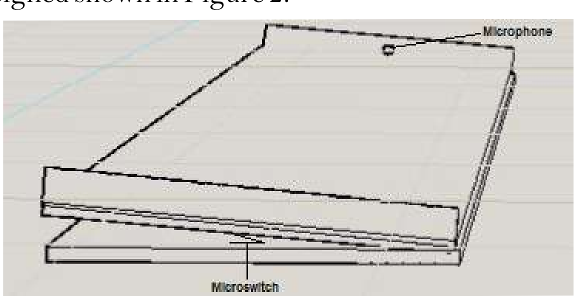

Figure 2. Experimental prototype. Source: own.

It is defined that the sleep sensor is installed under the pillow as support, taking measurements of the respiratory frequency of a person until detecting a regular breathing achieved when entering a state of sleep. The electronic construction of the sleep sensor is shown in the steps of the block diagram of Figure 3 and are explained below:

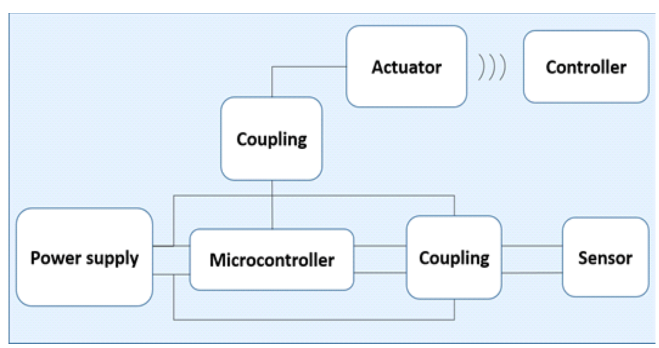

Figure 3. Block diagram. Source: own.

The sensor consists of two stages: one designed to detect the user's position, and the other to detect the sleep state by user´s breathing.
For positioning, the system has a microswitch installed in the base of the device shown in Figure 2, which makes the user detection function in the system, determining whether or not lying down. This pulse is used to initialize the detection stage.

The detection of sleep by means of regular breathing is sensed by FC-04 cards. They detect the respiratory rate by capturing the amount of exhalations per minute through high sensitivity microphones. These signals are processed by a microcontroller that compares the time intervals of each exhalation until finding a pattern where breathing becomes regular; it is at this moment when the system detects that the user is asleep, generating a pulse that is transmitted by means of a coupling circuit to the Z-Wave transmission module and at time to the main controller, with which the activation of the devices coupled to the domotic network.
For the start-up of the system a power supply of 5V - 200mA is dimensioned, this arrangement being necessary taking into account the purpose of achieving efficiency in the energy consumption of the design. Figures 4 and 5 show the final implementation of the prototype of the device.

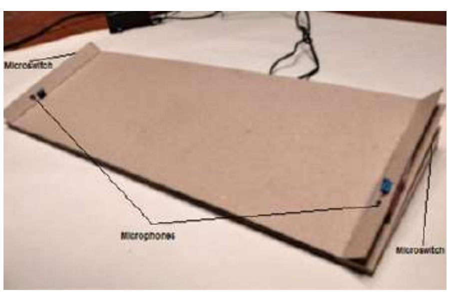

Figure 4 . Physical implementation of the prototype. Source: own.

Figure 5. Top view of the prototype with pillow. Source: own.

3. Tests and results

To verify the functioning of the system, a test was carried out with a person of 23 years, sensing their breathing at bedtime. For this, the respiratory frequency was measured with an audio recorder in parallel with the proposed sensor, the signal obtained was processed in the software "Free Audio Editor 2017" to analyze its behavior, Figure 6.

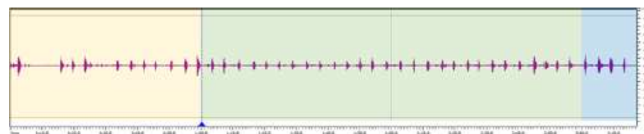

Figure 6. Respiratory frequency at activation time, Software: Free Audio Editor. Source: own.

The designed sensor takes the signal of the respiratory frequency and converts it into logical pulses where the exhalations are represented as shown in Figure 7.

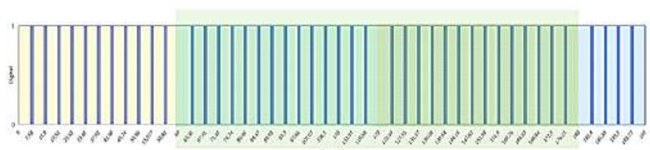

Figure 7 . Respiratory frequency in logical pulses. Source: own.

The Figure 7 shows the behavior of the exhalations, during three minutes, in the moment of activation where the equality of the number of logical pulses in minutes two and three is clearly seen. This equality is processed by the microcontroller which generates an activation signal that tells the home automation controller that the user entered a dream state to execute the programmed functions. Once the system is activated, the sensor will not take into account the number of pulses in the subsequent minutes while the user is lying down.

To guarantee that the system has an energy efficiency, consumptions have been studied that are generally not taken into account and present a significant energy spending; these consumptions correspond to a state of electronic devices when they are connected, but at rest mode and waiting to receive orders, called Standby. Considering this, they were made measurements of night consumption in a single-family house, to determine how much they correspond, approximately, the expenses in

Standby and the energy consumption of 1 and 4 TV sets on, because this is the most used electronic device before sleeping. Additionally, the percentage of savings represented by the implementation of the system in this house is calculated. The results of the measurements are shown in Table 1.

Description of Consumption	Voltage (Vac)	Current (A)	Power (w)	kWh / day	kWh / month	kWh / year	% savings[4]	Annual cost[5] (US $)
Standby	114	0,44	50,16	0,40	12,04	144,46	8%	22,60
Standby + 1TV On	114	0,71	80,94	0,65	19,43	233,11	13%	36,46
Standby + 4TV On	114	2,1	239,40	1,92	57,46	689,47	38%	107,84

Table 1 . Table of night consumption. Source: own.

Taking into account the key parameters that affect the user, and that are mentioned in the recommendation of ITU-T G.1010, tests were done using the Wireshark network traffic analyzer software to guarantee the correct functionality of the transmission and communication between the different stages of the prototype. Condensing the results of the implemented system, measurements of quality of service parameters are taken (QoS) related to Throughput, Delay and Jitter.

For that, 8 measurements are made for the activation state and 5 for the deactivation state, taking each sample in an interval of 300 seconds, and activating the TCP capture filter to achieve a selective capture of packages of this nature. The values measured by each of the parameters are listed below.

For the calculation of Delay the following formula is available (1), [22]:

$$Delay = \sum_{i=0}^{n} Ri - Si \qquad (1)$$

Where:

Ri it is the time of package reception

Si it is the package sending time

n is the number of packages

Figures 8 and 9 show the calculated delay results presented by the device in each of the samples taken. It is observed that the maximum delay is 15.19 ms for its activation, and 13.73 ms for its deactivation.

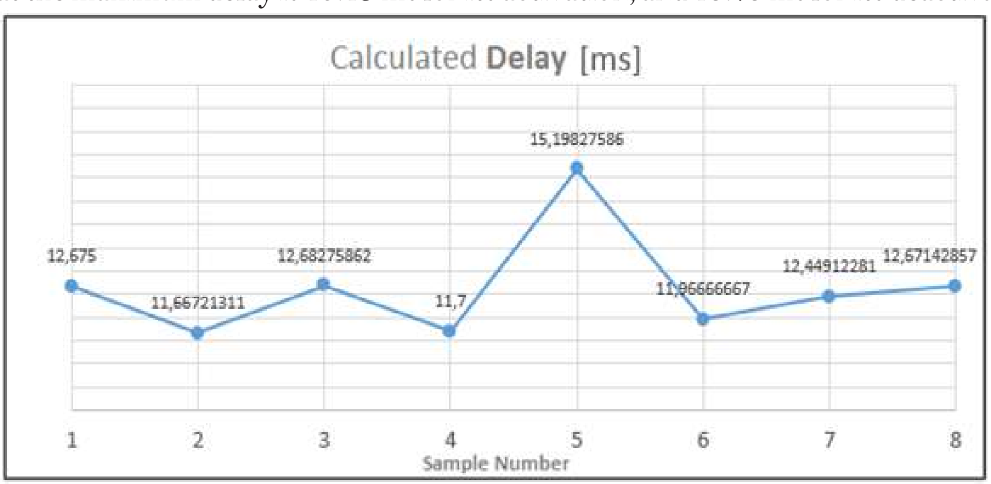

Figure 8. Calculated in activation state. Source: own

4 The saving is calculated according to an average monthly consumption of 150 Kwh/month

5 The annual cost is calculated according to the average cost of Kwh / month of 0.16 US$ for social strata 3

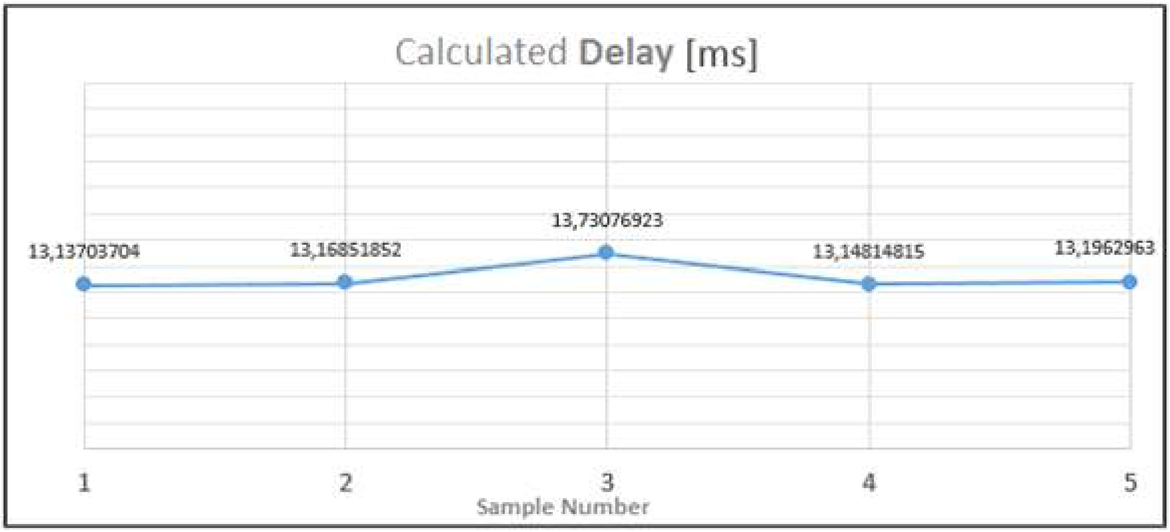

Figure 9. Delay calculated in deactivation state. Source: own.

When a packet delay varies unpredictably with its position in the queues along the path between the transmitter and the destination, the so-called Jitter is generated. The variation of delays is usually included as a performance parameter, since it is important, in the transport layer of the packed data systems, measure the inherent variability of the arrival times of the packages. We then proceed to find the parameter using the formula (2), [22]:

$$Jitter = \frac{\sum_{i=0}^{n}(R_i - R_{i-1})}{n} \qquad (2)$$

Where:
Ri is the reception time of the current package
Ri-1 it is the reception time of the previous package
n is the number of packages

Figures 10 and 11 show the results of Jitter.

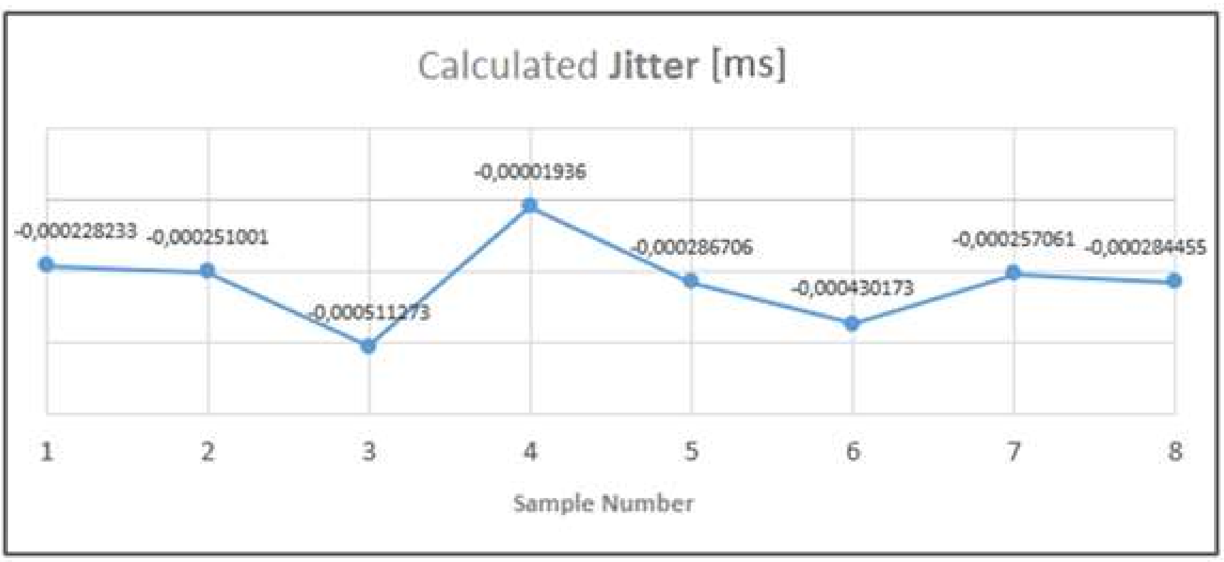

Figure 10. Jitter calculated in activation state. Source: own.

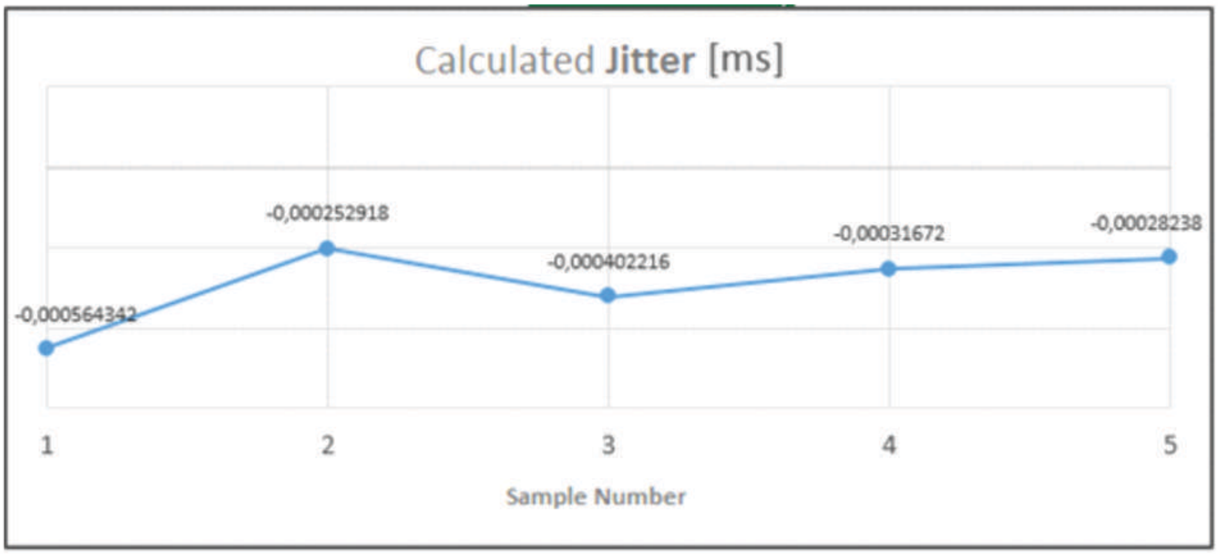

Figure 11. Jitter calculated in deactivation state. Source: own.

For the Throughput, known as the maximum production rate or the maximum rate at which information can be processed, we have the following formula (3):

$$Troughput = \frac{Package\ size}{Packet\ duration\ time} \quad (3)$$

Figures 12 and 13 show the result of the throughput measurements where it is observed that the maximum production rate of the system is 0.042 Mbps and the minimum rate 0.0310 Mbps in the activation state; and in state of deactivation a stability in the system of 0,037 Mbps is observed. Bearing in mind that the transmitted packets are control medium data, the efficiency of the system is sufficient for its correct operation.

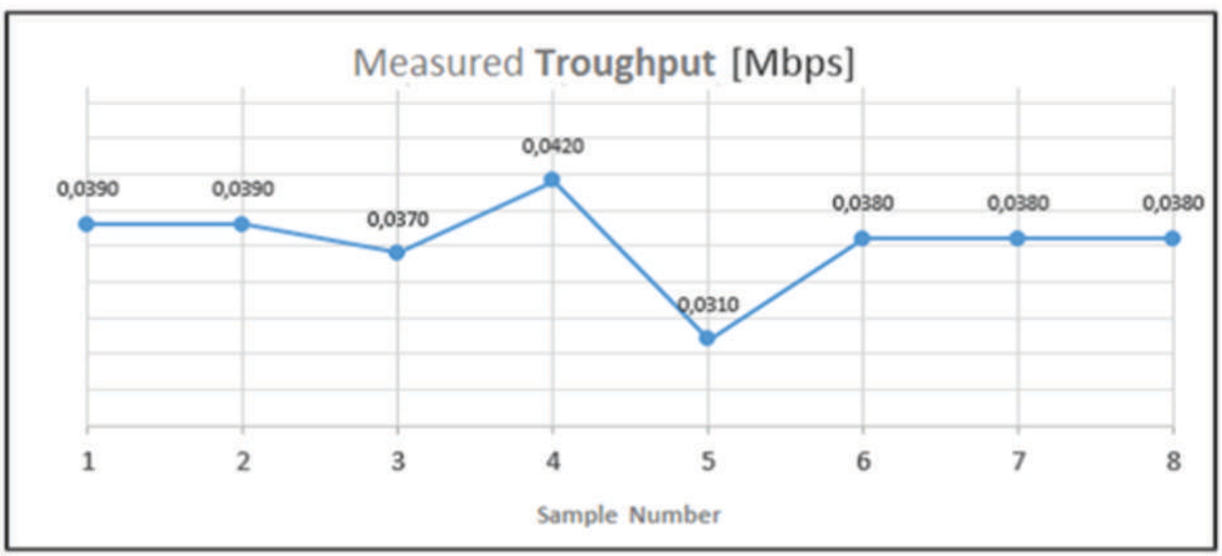

Figure 12. Throughput measured in activation state. Source: own.

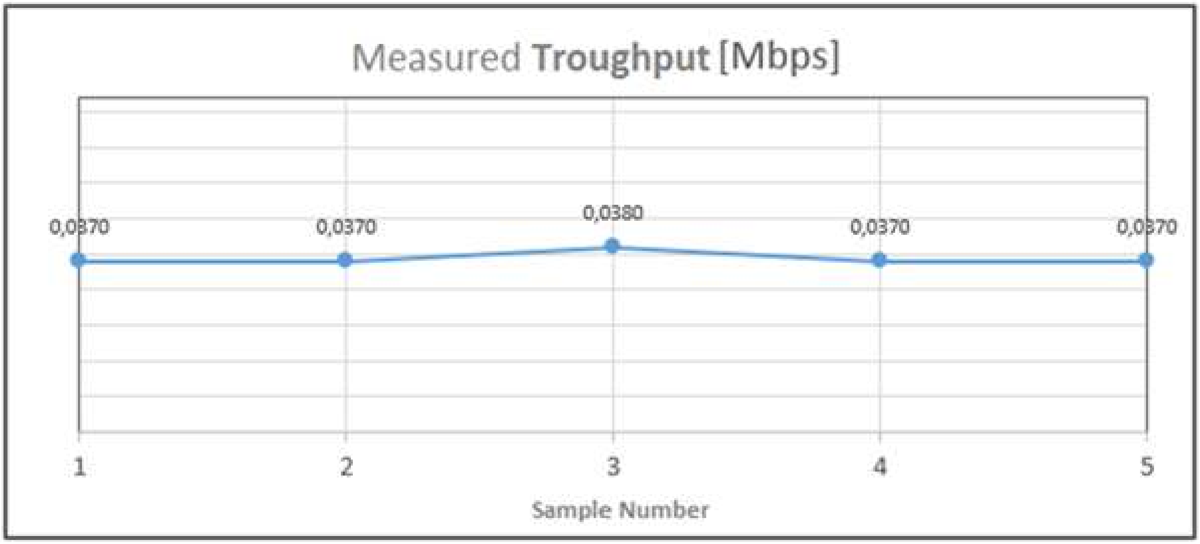

Figure 13. Throughput measured in deactivation state. Source: own.

4. Discussion

Of the tests carried out to determine the respiratory rate, it is found that the results obtained are within the parameters of a normal respiration for an adult person - that oscillates between 12 and 16 breaths per minute according to the Medical Center of the University of Rochester, [23].- This guarantees an optimal functioning of the sensor to measure the respiratory rate by means of microphones and to be able to determine the sleep state of a person.

According to the survey conducted on 1508 people by the National Sleep Foundation in 2011 about 60% turn on the TV one hour before going to sleep, [24].Taking this into account and applying the results of Table 1, we can estimate an approximate decrease in annual energy consumption per standby of 217846 kWh / year, if the 1508 people implemented the device in their rooms. In addition, if you take into account the probability that 60% of these people sleep with the TV sets on, implementing the device in these bedrooms can be estimated an additional savings in annual consumption of 80224 kWh / year.

For the parameters of quality of service it was obtained that the measured delay fulfills with the stipulated parameters according to the recommendation of ITU-T G.1010, where it is mentioned that for applications of directed way and control, the transmission time must be less than 250ms, [25]. Regarding the Jitter, figure 8, it is observed that the variation of the delays is negative because there is a stability, and in the following samples it is evidenced how the arrival time of the packages improves. Also the throughput is enough to guarantee a correct transmission of the sensor to the domotic controller.

5. Conclusions

The integration of the sleep state sensor with a Z-Wave home automation control increases the autonomy of the system, making it even more efficient, approaching truly intelligent systems that interact between man and machine. Although this prototype was designed primarily to obtain energy savings by disconnecting from the power supply any household appliance or device not essential to sleep, as indicated in table 1 where a saving of 38% is calculated when four televisions are turned on, It can also be used for security since when detecting a person sleeping the system can automatically turn on the perimeter sensors, activate an alarm, automatically close the doors, or turn off the gas appliances. All for the benefit of the user.

Additionally, the prototype can be taken as an instrument that indirectly contributes to improve the sleep quality and the user´s health since the system turns off the multimedia equipment in the room after a detection, thereby reducing noise, providing an environment conducive to rest taking into account that a person with poor sleep quality can get to suffer from different diseases including a possible brain atrophy, as mentioned by the study of the University of Oxford in its study of cortical atrophy, by the poor quality of sleep in adults,[26].

Finally, it is necessary to mention that from the analysis of the values obtained in the measurements of the parameters of quality of service it is observed that in them the sending and receiving of data are executed within a not very wide range and that therefore they are little noticeable to the user, which guarantees that the loss of information is null and that the implemented system is viable. In this way, compliance with the regulations that regulate the installation and operation of automated systems is met, as well as what is stated in the recommendation of ITU-T G.1010.

As future work will be proposed to use sensors that only detect the changes of respiratory frequency from sleep state to awake stake so that energy consumption is saved and at the same time the detection of the dream state is improved. In addition to this, it is necessary to improve the structural design of the device with the support of professionals in the area of industrial design in order to ensure that it is as ergonomic and comfortable as possible for the user. It is also necessary to develop applications that allow the integration of the sleep state sensor with different platforms dedicated to domotic control.

Acknowledge

We appreciate the collaboration of GIDENUTAS and SCIBAS research groups from Universidad Distrital Francisco José Caldas, for the support provided with the development of this research.

References

[1] Banco Mundial, "Población, total | Data," Https://Datos.Bancomundial.Org/, 2017. [Online]. Available: https://datos.bancomundial.org/indicador/SP.POP.TOTL

[2] Banco Mundial, "Consumo de energía eléctrica (kWh per cápita) | Data," World Bank Group, 2018. [Online]. Available: https://datos.bancomundial.org/indicador/EG.USE.ELEC.KH.PC%0Ahttps://datos.bancomundial.org/indicador/EG.USE.ELEC.KH.PC?locations=EC

[3] Z-Wave Alliance, "About Z-Wave Technology." [Online]. Available: https://z-wavealliance.org/about_z-wave_technology/

[4] ITU, "ITU-T G99.59 Short range narrow-band digital radiocommunication transceivers - PHY and MAC layer specifications," 2012.

[5] C. Wei, Y. Chen, C. Chang, and C. Yu, "The Implementation of Smart Electronic Locking System Based on Z-Wave and Internet," in 2015 IEEE International Conference on Systems, Man, and Cybernetics, 2015, pp. 2015-2017, doi:10.1109/SMC.2015.351. https://doi.org/10.1109/SMC.2015.351

[6] C. Yuan, H. Wang, and J. He, "Remote Monitoring System Based on MC9S12NE64 and Z-WAVE Technology," in 2010 International Conference on E-Product E-Service and E-Entertainment, 2010, pp. 1-4. https://doi.org/10.1109/ICEEE.2010.5661481

[7] Y. Hou, Y. Wang, and Y. Zheng, "TagBreathe: Monitor Breathing with Commodity RFID Systems," in 2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS), 2017, pp. 404-413. https://doi.org/10.1109/ICDCS.2017.76

[8] M. B. Yassein, W. Mardini, and A. Khalil, "Smart homes automation using Z-wave protocol," in 2016 International Conference on Engineering & MIS (ICEMIS), 2016, pp. 1-6,https://doi.org/10.1109/ICEMIS.2016.7745306

[9] K. Motoi et al., "A fully automated health-care monitoring at home without attachment of any biological sensors and its clinical evaluation," in 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2009, pp. 4323-4326, https://doi.org/10.1109/IEMBS.2009.5333712

[10] Mingjiang Wang et al., "A matress system for human biosignals monitoring," in Proceedings of the IEEE 2012 Prognostics and System Health Management Conference (PHM-2012 Beijing), 2012, pp. 1-5, https://doi.org/10.1109/PHM.2012.6228967

[11] G. Csernath, L. Szilagyi, G. Fordos, and S. M. Szilagyi, "A novel ECG telemetry and monitoring system based on Z-Wave communication," in 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2008, pp. 2361-2364, https://doi.org/10.1109/IEMBS.2008.4649673

[12] D. C. Mack, M. Alwan, B. Turner, P. Suratt, and R. A. Felder, "A Passive and Portable System for Monitoring Heart Rate and Detecting Sleep Apnea and Arousals: Preliminary Validation," in 1st Transdisciplinary Conference on Distributed Diagnosis and Home Healthcare, 2006. D2H2., 2006, pp. 51-54 https://doi.org/10.1109/DDHH.2006.1624795

[13] L. C. Chen, K.-W. Chen, and Y.-P. Hung, "A sleep monitoring system based on audio, video and depth information for detecting sleep events," in 2014 IEEE International Conference on Multimedia and Expo (ICME), 2014, pp. 1-6. https://doi.org/10.1109/ICME.2014.6890292

[14] J. Kempfner, P. Jennum, M. Nikolic, J. Christensen, and H. Sorensen, "Automatic detection of REM sleep in subjects without atonia," 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, vol. 5, pp. 4242-4245, 2012 https://doi.org/10.1109/EMBC.2012.6346903

[15] V. Gupta, S. Mittal, S. Bhaumik, and R. Roy, "Assisting humans to achieve optimal sleep by changing ambient temperature," in 2016 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), 2016, pp. 841-845, https://doi.org/10.1109/BIBM.2016.7822635

[16] N. Patwari, L. Brewer, Q. Tate, O. Kaltiokallio, and M. Bocca, "Breathfinding: A Wireless Network That Monitors and Locates Breathing in a Home," IEEE Journal of Selected Topics in Signal Processing, vol. 8, no. 1, pp. 30-42, Feb. 2014, https://doi.org/10.1109/JSTSP.2013.2287473

[17] P. Barsocchi, M. Bianchini, A. Crivello, D. La Rosa, F. Palumbo, and F. Scarselli, "An unobtrusive sleep monitoring system for the human sleep behaviour understanding," in 7th IEEE International Conference on Cognitive Infocommunications, CogInfoCom 2016 - Proceedings, 2017, no. CogInfoCom, pp. 91-96. https://doi.org/10.1109/CogInfoCom.2016.7804531

[18] R. Chen and Y. Lin, "Using ZeeBee Sensor Network with artifical neural network for indoor location," in 2012 8th International Conference on Natural Computation, 2012, no. Icnc. https://doi.org/10.1109/ICNC.2012.6234591

[19] K. Tonchev, P. Koleva, A. Manolova, G. Tsenov, and V. Poulkov, "Non-intrusive sleep analyzer for real time detection of sleep anomalies," in 2016 39th International Conference on Telecommunications and Signal Processing (TSP), 2016, pp. 400-404, https://doi.org/10.1109/TSP.2016.7760906

[20] M. Smolen, K. Czopek, and P. Augustyniak, "Non-invasive Sensors based Human State in Nightlong Sleep Analysis for Home-care," pp. 45-48, 2010.

[21] H. University, "Healthy Sleep," 2007. [Online]. Available. http://healthysleep.med.harvard.edu/healthy/science/what/characteristics

[22] I. Iskandar and A. Hidayat, "Analisa Quality of Service (QoS) Jaringan Internet Kampus (Studi Kasus: UIN Suska Riau)," Jurnal CoreIT, vol. 1, no. 2, pp. 2460-738, 2015.

[23] University of Rochester Medical Center, "Vital Signs (Body Temperature, Pulse Rate, Respiration Rate, Blood Pressure) - Health Encyclopedia - University of Rochester Medical Center." 2017.

[24] National Sleep Foundation, "2011 Sleep in America Poll," Washignton, 2011.

[25] UIT, "UIT-T G.1010 Categorías de calidad de servicio para los usuarios de extremo de servicios multimedios," 2001.

[26] C. Sexton, "Poor sleep quality is associated with increased cortical atrophy in community-dwelling adults," Neurology, 2014. https://doi.org/10.1212/WNL.0000000000000774