A technical solution for tourist beaches quality monitoring

Una solución técnica para el seguimiento de la calidad de las playas turísticas

L. L. Camargo-Ariza; M. C. Gasca-Mantilla; J. Gómez-Rojas
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***Abstract*—In terms of sustainability of tourist beaches, an impact factor is the measurement of parameters associated with ecosystem quality, sanitary quality and recreational quality. The measurement allows to identify the deterioration and the virtues of this type of beaches to make correct decisions about coast management. The paper presents the conditions and technical specifications of system monitoring for the beaches of Santa Marta city. The solution includes the sensor nodes, sink node, monitoring center, the mesh wireless sensor network and the radio links to interconnect the five beaches. To make the system viable, it was prototyped and tested. The distance between nodes of the mesh was determined on based in the measurements of received signal strength and lost packets, the modelling of the path loss and shadowing in wireless channel. The characteristics of radio links was established using the digital topography of the terrain and the Longley-Rice model. An average wireless channel attenuation of -42.46 dB, path-loss exponent of 2.08, Shadowing of 5.6 dB for beaches and distance between nodes is 130 meters were obtained. Additionally, seven radio links were parameterized for circumvent the hills of the Sierra Nevada de Santa Marta. For a triangular mesh and the selected devices, the tests gave 99.2% reliability. The results obtained support the implementation of the proposal.**

***Index Terms*— Beach quality, Channel Modeling, IEEE 802.15.4, LR-WPAN, Mesh networks.**

***Resumen*— En términos de sostenibilidad de las playas turísticas, un factor de impacto es la medición de parámetros asociados a la calidad del ecosistema, la calidad sanitaria y la calidad recreativa. La medición permite identificar el deterioro y las virtudes de este tipo de playas para tomar decisiones acertadas sobre la gestión del litoral. El trabajo presenta las condiciones y especificaciones técnicas del sistema de monitoreo para las playas de la ciudad de Santa Marta. La solución incluye los nodos sensores, el nodo sumidero, el centro de monitoreo, la red de sensores inalámbricos en malla y los enlaces de radio para interconectar las cinco playas. Para que el sistema fuera viable, se hizo un prototipo y se probó. La distancia entre los nodos de la malla se determinó en base a las mediciones de la intensidad de la señal recibida y los paquetes perdidos, a partir del modelo empírico de pérdidas simplificado y el sombreado en el canal inalámbrico. Las características de los radioenlaces se establecieron utilizando la topografía digital del terreno y el modelo Long ley-Rice. Se obtuvo una atenuación de canal inalámbrico promedio de -42,46 dB, exponente de pérdida de trayectoria de 2,08, sombreado de 5,6 dB para playas y una distancia entre nodos de 130 metros. Adicionalmente, se parametrizaron siete radioenlaces para sortear los cerros de la Sierra Nevada de Santa Marta. Para una malla triangular y los dispositivos seleccionados, las pruebas dieron un 99,2% de fiabilidad. Los resultados obtenidos apoyan la implementación de la propuesta.**

***Palabras claves*— Calidad de playa, Modelado de Canales, IEEE 802.15.4, LR-WPAN, Redes en Malla.**

I. Introduction

THE beaches are ecosystems that provide historical, cultural, recreational and economic resources [1, 2]. Despite management strategy and public policies, impact of climate, the anthropogenic influence and coastal erosion tends to affect these multidimensional systems [3, 4, 5]. For Colombia, tourism has become in a source of work and production, especially sun-and-beach tourism. Beach destinations are preferred by tourists when choosing their vacations. The beaches of the cities in Santa Marta, San Andres and Cartagena, are the favorites [6]. Around 600 thousand tourists regularly are received in Santa Marta during the vacation season. It is also a considerable source of pollution and degradation of the quality of their beaches, [7] affecting sustainable tourism development.

The tourism cities with that have urban sustainability problems have adopted initiatives associated with smart city label, and have even incorporated concepts such as smart tourism and smart destinations [8, 9]. These cities promote tourism competitiveness improvement processes with the integration, use and management of information technologies; technologies for: data collection, transmission of data, data storage and analysis, service delivery platform and, finally, smart city services [10].

On the other hand, the concept of quality of tourist beaches begins to be developed at the end of the 90s, as the basic tool to achieve sustainable development in the coastal zone [11, 12].

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L. L. Camargo-Ariza. is with the Faculty of Engineering, Universidad del Magdalena, Santa Marta 470004, Colombia (e-mail: lcamargoa@ unimagdalena.edu.co).

M. C. Gasca-Mantilla, is with Faculty of Mechanical, Electronic and Biomedical Engineering, Universidad Antonio Nariño, Santa Marta 470004, Colombia (e-mail: magasca@uan.edu.co).

J. Gomez-Rojas is with is with the Faculty of Engineering, Universidad del Magdalena, Santa Marta 470004, Colombia (e-mail: jgomez@ unimagdalena.edu.co).

However, there was no standard methodology to measure the deterioration and virtues of these types of beaches, so that their analysis focused exclusively on sanitary standards, which are not specific to recreational beaches. In 2008, a model that measures the Environmental Quality Index of Tourist Beaches of Colombia, ICAPTU, is proposed and in 2010 this model is updated and applied in the Colombian Caribbean, in what is known as ICAPTU-II [13, 14]. Finally, in 2015 the model is upgraded to ICAPTU-III using governmental norms [15]. This model must be fed with various parameters such as ecosystem quality, sanitary quality and recreational quality.

To achieve automatic supervision of the variables involved in the model and make the beach viable as a smart destination projecting a smart city, it is then necessary to design and implement a telecommunications network in accordance with the beach environment and the variables to be monitored. Wireless mesh networks have become an important option for the development of sensor networks, since they are relatively inexpensive, flexible and easy to develop [16]. In this kind of network, each station functions as a node and provides a relay service to other nodes, assuring more than one route between any pair of stations. This strategy solves two of the main problems of wireless networks: interference caused by other users in the same frequency band and scalability in geographical coverage. Additionally, ICAPTU-III measure the parameters in various positions on the beach at relatively short distances, with the purpose of establishing the gradients of some variables. That information does not require high rate transmission, but if its reliability. For the above reasons and the characteristics of the LPWAN (low-power wide-area network) and the LR-WPAN (low-rate wireless personal area network) [17]. The LR-WPAN technology based on the IEEE 802.15.4 standard and configured in mesh is use in the research.

Multiple applications of sensor network that implement these technologies to monitor the environment and cities are reported in the scientific literature [18, 19, 20, 21, 22, 23, 24, 25]. One of the challenges in the deployment of these systems is to determine the maximum distance between the transmitting nodes for optimal communication, due to the low transmission power and the propagation losses caused by the specific characteristics of the wireless channel of the environments where they are implemented. Path loss models are calculated and published for different scenarios: snowy environments [26], in rocky and mountainous environments [27], large-scale tree vegetation terrains [28], mixed forest [29], with transmitters near-ground [30], agricultural fields [31], short and tall natural grass environments [32], urban intersections [33] and parking [34]. For this application of sensor networks it is necessary to obtain a model for tourist beaches.

The most significant reference is a previous study by the authors [35] in this which the viability of the mesh network for sensors on the beach and is evaluated and the distance between nodes in the mesh is estimated for the first time. This paper taking into account only of the measurements made in one beach of the city, the test is only carried out by transmitting two variables ICAPTU, prototype with a lower level of technological maturity are used. Further, the analysis to connect the beaches and the monitoring centre is not included.

This work shows the development of the wireless telecommunications network that supports the transmission of the parameters to feed the ICAPTU III model, such as relative humidity, temperature, Co2, atmospheric pressure, solar radiation, solid waste monitoring, user density and, PH, coliforms of water and sand. The prototypes of sensor node and sink node is developed to test the operation of this network. The sensor node implemented only has with measurement of parameters captured on the beach that do not require an additional signal processing to obtain the information. The solid waste monitoring, the user density and the coliforms and pH are discarded.

The proposal consists of a mesh-type sensors network on the beach and the radio links between the beaches and the monitoring centre. The distance between nodes in the mesh is calculated from the development of a path loss model in the beach. The parameters of the radio links point to point are calculated from the Longley-Rice loss model and digital topography.

II. Materials and Methods

This is a fundamental, explanatory, and quantitative research that aims to establish design parameters and optimal operating conditions to connect the sensors on the beach with a monitoring center. These parameters and conditions are focused on sustaining future teleservices for ICAPTU.

The research includes the study of coverage, prototype and testing of a mesh network for sensors on the beach, and the design of the point-to-point radio-electrical link between the monitoring center and the beaches. The methodological design is: (i) implement the monitoring center prototype and the prototypes of the sensor node and the coordinating node, (ii) characterize the wireless channel (beach environment) using the simplified loss model, (iii) determine the optimal distance between nodes and define the location of the mesh points on the beach, (iv) test the operation of the network, and (v) determine the specifications of the point-to-point links between the beaches and the monitoring centre.

A. *Prototyped of the system*

To elaborate the prototypes, it is develops: (i) the functional requirements of the sensors, the network and the system in general are identified, (ii) the conceptual design and the technical feasibility are developed, and the technologies are selected, (iii) the execution is projected, the hardware parts are assembled, and the software is implemented, and (iv) the prototype is tested and fed back to obtain an operational level of the products.

The sensor node consists of: the sensors, a single-board computer (Raspberry Pi) or a microcontroller (Mega Arduino), and a router for mesh (LR-WPAN). The sensors are connected to the microcontroller using the universal asynchronous receiver-transmitter (UART) mode, the serial peripheral interface ISP, the bus I2C, USB or analog inputs on the board, fulfilling the communication requirements of commercial sensors. The router is based on the IEEE 802.15.4 standard and the ZigBee specification (XBee) in the frequency of subGhz (2.4G Hz). This is programmed using AT commands and connects to the Raspberry Pi through the USB or the microcontroller through the shield, (see Fig. 1).

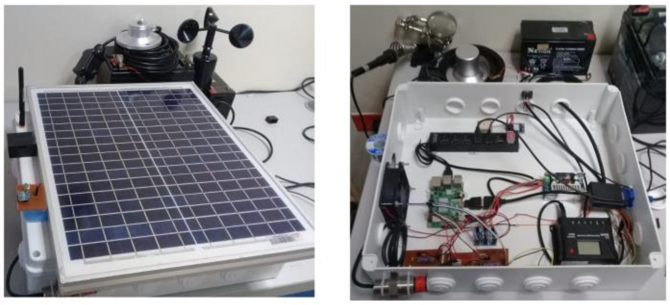

Fig. 1. Construction of the sensor node prototype.

The sink node or coordinating node consists of: a coordinating for mesh (IEEE 802.15.4 - ZigBee – Xbee), a single-board computer (Raspberry Pi), and an IEEE 802.11ac radio. The communication between the Raspberry Pi and the IEEE 802.11ac radio is done with the IEEE 802.3 standard.

Mesh network for test is implemented with three sensor nodes and one coordinating node. The network is managed for guaranteeing scaling and self-configuration in case a network node fails. A network architecture is proposed and is shown in Fig. 2.

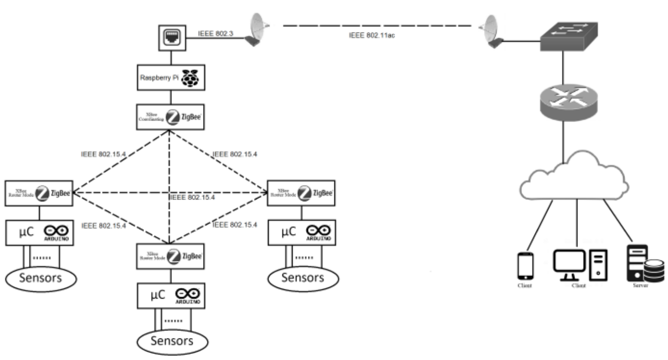

Fig. 2. Schematic of the prototype. The image on the left refers to the beach and the image on the right refers to the monitoring center.

In all sensor node the variables are sampling every five minutes and the data obtained are unified in a single format georeferenced and associated with time, next this is temporarily stored until it is sent. With the proposed network architecture and taking into account the relatively small size (< 1k bits) of the format, and data rate RF 250 Kbps and serial up to 1 Mbps, it is possible to send the variables information before the next sample, for a large number of connected sensor nodes (< 254).

The energy system on the beach for the sensor nodes and the coordinating node are integrated by polycrystalline solar photovoltaic module of 20Wp to 12V, AGM technology sealed battery of 35Ah to 12V for 2 day of autonomy, PWM charge regulator of 10A to 12V, DC - DC converter 12V - 5V.

Monitoring center is made up of the an 802.11ac radio, the necessary network devices, the server, and the client's final device, (see Fig. 2)

Once the communication is established, the sensor information obtained from the router nodes is sent to the server through the coordinating node. The information is in light text, with JavaScript Object Notation (JSON) format. The HTTP protocol with the POST method is used in this transmission.

The server that is open source, was coupled to this project with functions specific to the needs of the sensor network. One of its functions is to automatically register and store the sensor information that is in the JSON format. To avoid conflict and replication of the information, the server verifies that the data received has the corresponding format and its respective identifier. Another of its functions is to respond to requests made by users through the Web interface through the HTTP protocol using the GET method, on the data collected by the sensors.

The graphical interface was made through the HTML language, and it is hosted on the implemented server. In this interface, the values of the online variables taken by the sensors are observed, in addition to generating and downloading the historical records in a .csv file for each variable.

B. Wireless Channel Modelling

The Simplified Path-Loss Model is used to estimate the power received at the receiver as a function of distance [36], (1).

$$P_R = P_T G K \left[\frac{d}{d_0}\right]^n \tag{1}$$

Where: PR, is received power. PT, is transmitted power. K, represents the average channel attenuation. G, is the product of the transmit and receive antenna field radiation patterns in the LOS direction. n, is the path-loss exponent that depends of the frequency and the medium in which it develops the transmission. d is the final coverage distance. d0, is distance for the antenna far field and the initial sampling distance reference. The values for K, d0, and n can be obtained of by way of measurements and analytical equations.

In dB is thus, (2).

$$\begin{aligned} P_R(dBm) = P_T(dBm) + G_T(dBi) + G_R(dBi) + K(dB) \\ + 10n\,\mathrm{Log}_{10}\left[\frac{d}{d_0}\right](dB) \end{aligned} \tag{2}$$

For the analysis, it is necessary to consider radio parameters of the XBee 3 module, used for the links of the proposed architecture. Radio interface data provided by the manufacturer, detailed in Table I [37].

TABLE I
XBEE 3 MODULE DATA

PARAMETER	**VALUE**
Power transmitter	+8 dBm (6.3 mW)
Receiver sensitivity	-103 dBm (1 % PER, package lost)
Supply voltage	2,1 V – 3.6 V
Data Rate	RF 250 Kbps, serial up to 1 Mbps
Operating frequency	ISM 2.4 GHz (16 ch.)
External Antenna	2.1 dBi

The sites chosen to perform measurements was the Rodadero beach and the Taganga beach in the city of Santa Marta (Colombia). The height of the transmitter and receiver is 2 meters. The Radio Range Test of Digi tool is used for the measure the Received Signal Strength Indicator, RSSI or PR. An d0 of 3 meters was taken, because at smaller distances RSSI does not vary significantly with the variations of the distances, the average result in this distance is an RSSI of -36 dBm. Subsequently, measurements were made every 3 meters' whit various sampling per position, according to the recommendation given by [38, 39]. The mean value of the RSSI is used for modeling and is detailed in Fig. 3.

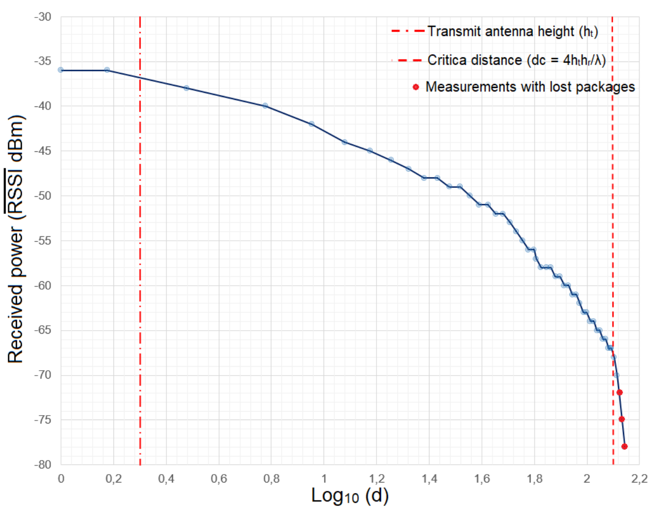

Fig. 3. RSSI, Received Signal Strength Indicator. The red points are RSSI measurements with loss packet of data.

The Fig. 3 shows that the received power decreases as a function of distance of three different shape, in the first section this variation is faint, the second segment has a considerable slope, and the last section the received power is strongly decreases. The measurements made after 130 meters registered lost packets, these correspond to the third segment, this distance is close to the critical distance where ground reflection dominates the multipath effect and components only combine destructively, as established by the Two-Ray Model [36, 40].

Transforming the independent variable d to ($\log_{10}[d/d_0] = x$) and replacing (P_T = 8 dBm, G_T = 2.1 dBi, G_R = 2.1 dBi)

The propagation losses regardless of the power of the RF power device and the antennas used are shown in (3) and (4).

$$L\,(dB) = P_R - 12.2 \tag{3}$$

$$L\,(dB) = K + 10n(x) \tag{4}$$

Simple linear regression of the data is used to obtain las constants k and n, this is shown in Fig. 4, (see (4)). The measurements with lost packages and measurements taken at distances of less than three meters are excluded in the modelling.

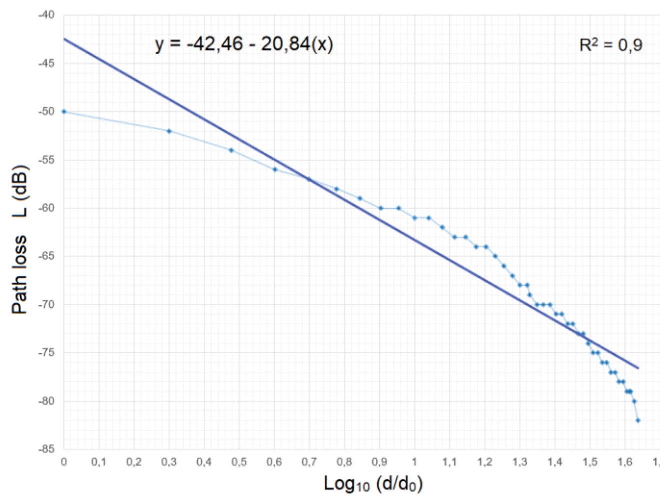

Fig. 4. Path-Loss model. The line with points represent the measurements and the continuous line represents RSSI calculated with the mathematical model.

The result is shown in the (5). The determination coefficient is R^2 = 0.909, therefore the model is validated.

$$\mathrm{L}\,(dB) = -42.46 - 10(2.08)\,\mathrm{Log}_{10}\left[\frac{d}{3}\right] \tag{5}$$

The sample variance relative to the simplified path-loss model is of σ^2 = 6.04 (6), and the standard deviation of σ = 2.45 in dB.

$$\sigma_{dB}^2 = \frac{1}{N}\sum_{i=1}^{N}[L_{measured} - L_{model}]^2 \tag{6}$$

The residuals are examined evaluating that they follow a normal distribution with zero mean (0,081), using the Shapiro-Wilk and Kolmogorov-Smirnov tests with the Lilliefors correction.

In (7) is illustrates combination of path loss and shadowing.

$$L\,(dB) = -42.46 - 10(2.08)\,\mathrm{Log}_{10}\left[\frac{d}{3}\right] - \psi_{dB} \qquad (7)$$

Where ψ_{dB} is a Gauss-distributed random variable with mean zero and variance σ2, (8). This is loss relative to median path [41].

$$Prob(\varphi_{dB}) = \int \frac{1}{\sigma_{\varphi_{dB}}\sqrt{2\pi}} e^{-\frac{\left(\varphi_{dB}-\mu_{\varphi_{dB}}\right)^2}{2\sigma_{\varphi_{dB}}^{\ 2}}} d\varphi_{dB} \qquad (8)$$

For a $\sigma = 2.45$ the loss relativa to the median path is great than 5.6 dB only 1% the time, thus the loss relative is of $\psi_{dB} = 5.6\ dB$.

C. Distance Between Nodes in the Mesh and Location of Mesh Points on the Beach

The sensitivity of the device delivered by the manufacturer is checked under operating conditions. Therefore, tests of the implementation site are performed. By varying the power for which the device performs the discovery and pairing a measurement campaign is carried out. According to this procedure, the value of the received power with which a transmission is made without lost packets is -70 dBm (9). This is a difference of 33 dBm with that established in the Datasheet.

$$-70\ (dBm) < \left(8 + 2.1 + 2.1 - 42.46 - 10(2.08)\,\mathrm{Log}_{10}\left[\frac{d}{3}\right] - 5.6\right) \qquad (9)$$

The (10) gives a maximum distance of d < 131,36m. Using this distance between nodes and performing connectivity tests between the network devices, it is appreciated that there is an assurance in the transmission at the packet level.

The site chosen for the implementation of the prototype of the mesh was the Rodadero beach. The Rodadero beach is one of the popular beaches in Santa Marta for the tourists This beach is approximately 1.6 Kilometers long and 240 meters wide.

A triangular mesh is chosen for the sensor network, with equilateral triangles of 130 meters on each side. Because each node of the mesh is equidistant from 6 underlying nodes, increasing the reliability of the connection. For testing is implement 4 nodes of the mesh, see Fig. 5.

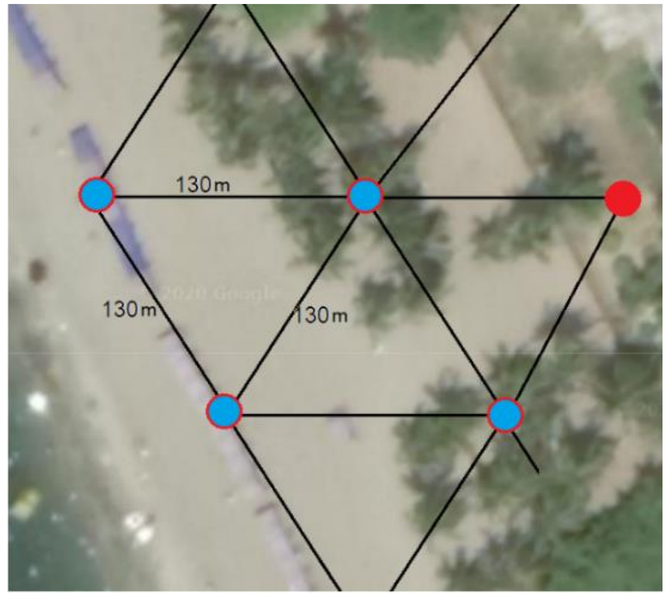

Fig. 5. The mesh network on Rodadero beach model.

D. Functional Tests for the Sensor Network

The different tests are performing out in a real environment with the purpose of establishing the viability of the network of seniors on the beach. These are: measurement of BER, measurement of RSID, connection validation, and communication validation.

E. Connection Between the Beaches and the Monitoring Center

RadioMobile software is used to determine the specifications of the point-to-point links (802.11ac) required to connect the network of sensors on the beach with the monitoring center. The procedure applies to the beaches of the city of Santa Marta. This city is located between the Caribbean Sea and the Sierra Nevada de Santa Marta. The most popular beaches in the city are: Rodadero, Taganga, Bello Horizonte, La Bahía, Bahía Concha. Most of these beaches are surrounded by hills that obstruct the line of sight.

The location of the communication radios required to connect the beaches with the monitoring center is determined, the propagation losses are calculated based on the digital topography of the terrain and the Longley-Rice model (Software RadioMobile). Subsequently, the power balance is performed using the characteristics of the test equipment, and the required configuration for correct operation is established.

III. Results and Discussion

A. Wireless Channel Model for the Beaches

Wireless channel model for narrowband communication is obtained from measurements, statistical analysis and test in the environment, Table II.

TABLE II
WIRELESS CHANNEL MODEL FOR BEACHES

PARAMETER		VALUE
The average channel attenuation	K	-42.46 dB
The path-loss exponent	n	2.08
The initial sampling distance reference	d0	3 meter
Standard deviation	σ	2.45 dB
Shadowing	ψ	5.6 dB

This model can be used to estimate the propagation losses as a function of distance on tourist beaches at a frequency of 2.4 Ghz and regardless of: the RF device manufacturer, the transmitter power, the receiver sensitivity and the implemented antennas.

The model parameters are similar to the models made by the IEEE 802.15.4a working subgroup [42] but, these do not present the same performance as the one presented in this work. Outdoor LOS and Snow-covered open area are the models with the less standard deviation with respect to the data taken on the beach, how to appreciate it in Table III.

TABLE III
IEEE 802.15.4A MODEL PARAMETERS

ENVIRONMENT	*K*	*n*	*σ for beach*
Residential LOS	-43.9 dB	1.79	3.48 dB
Residential NLOS	-48.7 dB	4.58	38.4 dB
Indoor office LOS	-35.4 dB	1.63	13.03 dB
Indoor office NLOS	-57.9 dB	3.07	28.02 dB
Outdoor LOS	-45.6 dB	1.76	2.87 dB
Outdoor NLOS	-73 dB	2.5	35.8 dB
Snow-covered open area	-48.96 dB	1.58	3.1 dB
Industrial LOS	-56.7 dB	1.2	5.2 dB
Industrial NLOS	-56.7 dB	2.15	15.26

None of the other loss-of-route models cited and used in other settings comes close to the measurements found on the beach.

B. *Mesh Network Test*

To test that the mesh configuration works correctly, two router nodes and a coordinating node were used. The router nodes sent information to the coordinator and this is displayed by the serial port of the coordinator node, to check the arrival of the coordinator.

Initially you have the router E-1, with a separation distance with the coordinator C of 130 meters. Then, the E-1 is moved away from C until the intensity of the received signal decreases and it loses communication. therefore, the data will not be able to be transmitted, the distance in which the E-1 loses range was around 136 meters. Later, another router node is added to the network (E-2). The E-2 transmits the data from the sensors at point 2 and is a bridge between node E-1 and node C. This allows communication to be restored between E-1 and C. Another test carried out is to generate shadow to node E-1 so that it loses connection with C, then E-2 is enabled in the network and it is verified that the communication of E-1 with C is restored through node E2. The Fig. 6 illustrates the tests.

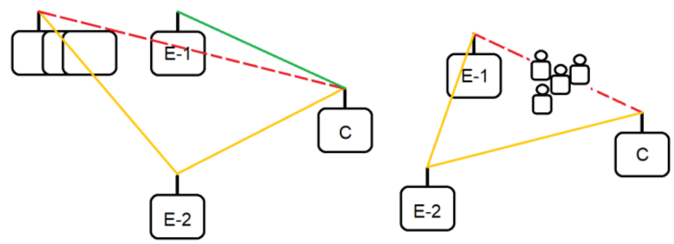

Fig. 6. Mesh test. (a) Path-Loss. (b) Shadowing.

Communication tests were carried out between the sink node and the server, between the sensor nodes, and between sensor node and the server. The results were successful. In the left part of the Fig. 7 shows the test

Additionally, it was used the XCTU software from the manufacturer of the DIGI devices, it was evaluated the packets sent and received in the estimated range (130 meter), obtaining a reliability of 99.2%. These tests are performed on the beach and in the presence of bathers (see Fig. 7b).

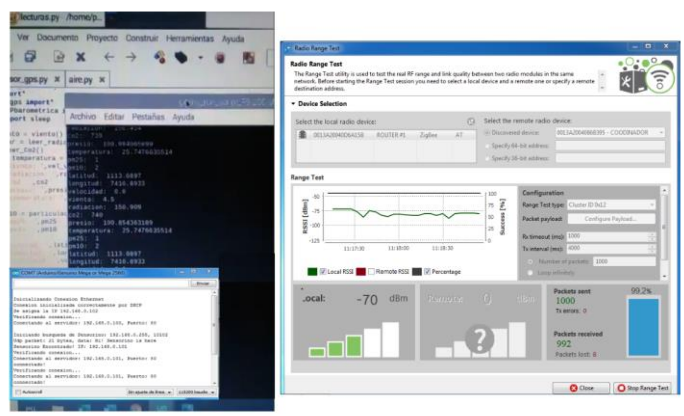

Fig. 7. Communication test. (a) Connection test. (b) packets sent and received test.

C. *Simulation of radio links*

To connect the beaches with the monitoring center (Universidad del Magdalena, UNIMAGDALENA), it is necessary to implement radio links. The La Bahía beach and the University have line of sight. The Rodadero, Taganga, Bello Horizonte, and Bahía Concha beaches do not have a line of sight with the University, so it is necessary to install repeaters. Considering the digital topography of the land, is recommended to install two base stations for the radio repeaters. The north base station (RPT NORTE) to connect the Taganga and Bahía Concha beaches with the University. The south base station (RPT SUR) to connect Rodadero and Bello Horrizonte beaches with the University, Fig. 8.

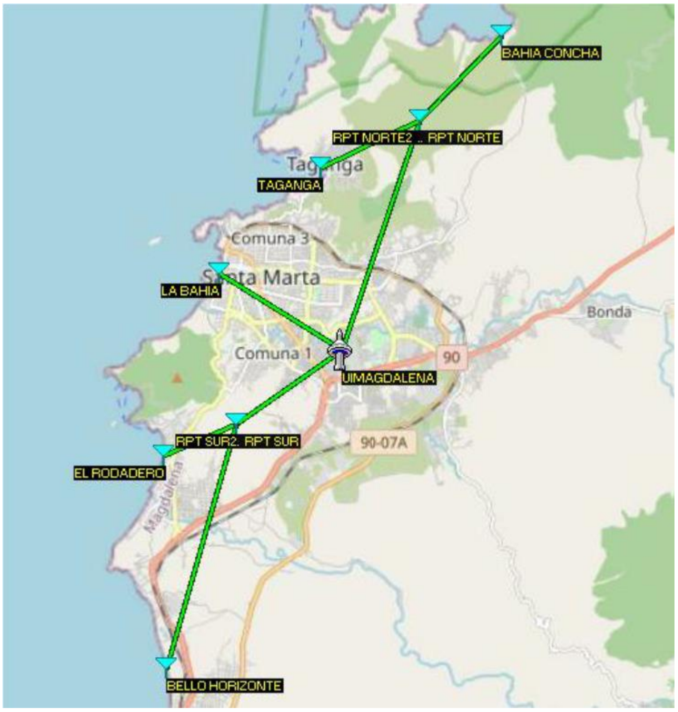

Fig. 8. Location of radio links. The repeaters are marked with the letters RPT.

The specifications of the radios are: power 27 dBm, antennas heights 10 m, antennas gain 16 dB, line loss 1 dB, sensitivity -94 dBm. The characteristics of the links are obtained using the Radio Mobile software. These are summarized in the Table IV.

TABLE IV
CHARACTERISTICS OF RADIO LINKS.

Link	Coordinates	Distance	Azimuth	Elev. angle	L (Free Space)	Worst Fresnel	L (Longley-Rice)	Rx Level
The monitoring center (UNIMAGDALENA) – The La Bahía beache	11°13'33"N 74°11'12,7"W - 11°14'35,6"N 74°12'54,8'W'	3.65 km	302°	0.311°	118.5 dB	0.8 F1	120.9 dB	-63.9 dBm
The monitoring center (UNIMAGDALENA) – The north base-station (RPT NORTE)	11°13'33"N 74°11'12,7"W - 11°16'40,9"N 74°10'7,4"W	6.13 km	18.81°	5.22°	123 dB	5.8 F1	132.5 dB	-75.5 dBm
The north base station (RPT NORTE) - The Taganga beache	11°16'40,9"N 74°10'7,4"W - 11°16'1,7"N 74°11'29,6"W	2.76 km	244.07°	-11.98°	116.3 dB	3.2 F1	123.6 dB	-66.6 dBm
The north base station (RPT NORTE) - The Bahía Concha beache	11°16'40,9"N 74°10'7,4"W - 11°17'49,6"N 74°8'58,3"W	2.98 km	44.59°	-11.09°	116.9 dB	2 F1	124.5 dB	-67.5 dBm
The monitoring center (UNIMAGDALENA) – The south base-station (RPT SUR)	11°13'33"N 74°11'12,7"W - 11°12'31,9"N 74°12'40,3"W	3.25 km	234.6°	5.93°	117.5 dB	9.4 F1	122.4 dB	-65.4 dBm
The south base station (RPT SUR) - The Rodadero beache	11°12'31,9"N 74°12'40,3"W - 11°12'5,8"N 74°13'41,3"W	2.01 km	246.42°	-9.79°	113.5 dB	3.9 F1	115.4 dB	-58.4 dBm
The south base station (RPT SUR) - The Bello Horrizonte beache	11°12'31,9"N 74°12'40,3"W - 11°9'11,3"N 74°13'39,2"W	6.45 km	196.06°	-3°	123.4 dB	1.5 F1	130.9 dB	-73.9 dBm

IV. CONCLUSION

It is possible to implement a wireless, flexible and reliable sensor network on a tourist beach to transmit the information provided by various sensors that measure the quality of the beach to a monitoring center; through nodes configured in mesh type network and separated 130 meters from each other and a coordinator connected to the Internet.

The wireless channel model for narrow-band communication on the beach obtained presents better performance compared to those of the IEEE 802.15.4a channel model final report. Furthermore, it is similar in its path loss exponent and in its average channel attenuation to the LOS models, especially in the outdoor LOS and open snow covered areas.

The prototype's polycrystalline photovoltaic solar module is the largest component of the sensitive node (0.15 m2). It causes little visual pollution, due to its size and the small number of mesh nodes required on the beach. This could be replaced and the rechargeable batteries of these nodes could be renewed each time they are exhausted, considering their low energy consumption.

The radio links in IEEE 802.3 enable the continuous sending of images and videos of the beaches in addition to the data obtained from the sensor network. To only transmit the data from the sensors, the networks of cellular mobile phone operators or other technologies that are previously installed could be used.

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Luis Leonardo-Camargo Ariza is an electronic engineer, master in electronic engineering and doctor of science, mention in management. He is a tenured professor at the Universidad del Magdalena and a member of the Research Group on Electronic Development and Mobile Applications (GIDEAM) of this institution.

ORCID: https://orcid.org/0000-0002-7956-441X

Maira Cecilia Gasca-Mantilla is an electronic engineer, has a master's degree in maintenance and a doctor of science, mention in management. She is an assistant professor at the Antonio Nariño University and a member of the REM, Research on Energy and Materials. Research Group of the same institution.
ORCID: https://orcid.org/0000-0003-0801-1161

Jorge Gómez-Rojas received his degree in Electronics Engineering in 1999. He graduated in 2003 as a Teleinformatics Specialist. He obtained a Master degree in Electronics Engineering in and a PhD in engineering in 2018. He is currently a tenured professor at the University of Magdalena, lider of the Research Group GIDEAM. He is a peer reviewer for Colciencias and IEEE Senior Member.
ORCID: https://orcid.org/0000-0002-0840-8743