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CONFERENCE PAPER · AUGUST 2013

DOI: 10.1109/SASE-CASE.2013.6636769

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Characterization of LQI behavior in WSN for glacier area in Patagonia Argentina

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***Abstract*—One of the most important aspects before installing a Wireless Sensor Network (WSN) is a previous study of connectivity constraints that exist in the area to be covered. This study is critical to the final distribution of the sensors, with an important impact in the life of the network by reducing consumption, and on the robustness by contemplating redundancy of paths and sensors. In this paper, we present a summary of the most important aspects of a preliminary empirical study of the Link Quality Indicator (LQI), on different landscapes in the glaciers area of Patagonia Argentina. The landscapes covered varied in geographical structures with different levels of attenuation and extreme environmental conditions. Through the analysis of the Cumulative Distribution Function (CDF) of the measured LQI values, we can characterize the behavior of four different scenarios and correlate the combined effects of the environmental structure with the distance from the transmitter. The measurements performed were designed for characterizing the links at the physical layer with the purpose of defining models to estimate the Packet Error Rate (PER) for the WSN deployment stage.**

***Keywords*-LQI, Nothofagus, WSN, WPAN, 802.15.4, Moraine, Glacier, Forest.**

I. Introduction

In the province of Santa Cruz, Patagonia, Argentina, researchers of IANIGLA - CONICET (Argentine Institute of Snow Research, Glaciology and Environmental Sciences - National Scientific and Technical Research Foundation) [1] carry out a research on the study a native plant species like the Nothofagus Pumilio, also known as Lenga. The IANIGLA researchers are interested in understanding in detail how the Lenga is affected by environmental parameters such as ambiental and soil temperature and humidity, at small scale in the Nothofagus Pumilio seedlings, particularly in Moraines and in the high-altitude forest boundary termed treeline [2]. This would require environmental information captured between spring and autumn, which is currently obtained through individual data loggers located in the vicinity of the area of study.

Data loggers are expensive instruments that have low robustness, limiting the number of measurement points and the data recovery in case of an incident. A better alternative involves the installation of a WSN [3]. These networks consist of spatially distributed nodes, also called motes, each of which is equipped with sensors, memory for storage, processor for computing their decisions, batteries for energy supply and are able to communicate wirelessly with other nodes in a short-range. In this work we consider a special case of WSNs: wireless personal area networks (WPAN). The advantage of these type of WSNs is to allow obtain data and a greater precision of the measured parameters (temperature, humidity) for the development of a microclimate-analysis with a higher density of measurement points.

During the first measurement campaign in January 2012, the LQI measurements obtained covered to the entire area of interest, considering the obstacles that alter the reception. Low LQI values are associated with low signal strength and/or high signal distortions, mainly caused by interference signals and/or multipath. On the other hand, high LQI values indicate a sufficient high signal power and low signal distortions. In particular, the propagation model used is low height, between the ground level and a maximum of 1.2 m in a tree trunk. However, the irregular terrain and the existence of large-sized stones generate more complex shading with multipath reflections, degrading the signal quality.

Because of this underlying complexity, along with the associated variability of the attenuation produced by dominant surface vegetation; theoretical modeling would be of little effectiveness. As a result, it is vital to understand the empirical behavior of the link quality estimator in the field. Field measurements of signal strength can be performed through dedicated and specialized instrumentation. Although this may result in more precise measurements, they can be misleading as they may not reflect the actual signal strength or quality estimators detected by the motes of the WSN. As an alternative, a more realistic approach consists in measuring and reporting the LQI as measured by each mote, reflecting the actual received signal distortion at the nodes of a deployed WSN. Different deployment scenarios were considered, based on the needs and concerns of the IANIGLA researchers. These scenarios are described in detail in Section V-B.

The rest of this document is structured as follows: Section II presents related work in the area, section III describes the communication protocol used, section IV provides detailed information on the hardware used in our empirical study, section V describes our experimentation methodology, and section VI and VII presents our results, conclusions and future work.

II. Related Work

WSNs have been deployed for several environmental and earth observation studies. An overview of implementations for climate monitoring, disaster early warning prevention, precision agriculture and pollution monitoring are widely discussed in [4]. Specifically, on the ecology area, the performance of links on the 2.45 GHz band through Radiata pine tree was evaluated in [5] to determine wood moisture content; the estimation of WSN coverage on Oak trees and Eucalyptus was studied on [6], and further extended for peer-to-peer tests in [7]; a study case on mango and oil palm is presented in [8] and finally [9] uses a ZigBee-enabled WSN to demonstrate that in environments with vegetation such as trees, the vertical positioning of the nodes above the ground may have an important effect on the attenuation. The common factor among the former studies is the use of received power value as a predictor of Packet Error Rate. Nevertheless, with the inception of the 802.15.4 standard, the new measurement, LQI becomes available as a better predictor than received power value [20]. Studies about LQI in indoor environments can be found in [10], [11] and [12]. To the best of our knowledge the use of LQI to characterize different environments in Glacier area, has not been published yet.

III. Communication Protocol

The protocol that defines the data communication between devices using low power, low data rate and short-range wireless transmissions in a WPAN is the IEEE 802.15.4 standard [13]. This standard defines only the low layers: physical layer and media access control sublayer (MAC). WPAN is not unique in this sense, several other protocols for wireless data transmission – 6LoWPAN, ZigBee and RF4CE – are based on 802.15.4 MAC as subjacent protocol layer.

Only two nodes configurations are allowed in 802.15.4: Full Function Device (FFD) and Reduce Function Device (RFD). A FFD device works as a network coordinator, taking the PAN coordinator role, and can communicate with others nodes. On the other hand, the RFD devices can only communicate with a FFD device and are not allowed to act as a coordinator. The nodes can communicate using the star topology or peer-to-peer topology. For more advanced routing topologies other standards are needed – e.g., 6LoWPAN, ZigBee or RF4CE – or user made upper layers.

IV. Hardware Settings

Two nodes of type RCB230 Radio Controller Board V3.2 [14] were used for the link quality measurements, which are 2.4 GHz radio modules that have an AVR AT86RF230 transceiver [15] according to the IEEE 802.15.4 standard specifications [13] for wireless personal area networks and low data transfer rate and a low-power ATmega1281V microcontroller. For retrieving the measurement output, the FFD node was connected to a laptop via USB through the Sensor Terminal Board [16]. The RFD devices were supplied with two AAA lithium batteries each.

V. Experiments

A. Measurement Procedure

For each scenario, the FFDs position was fixed and the RFD was placed on different points of interest. The transmission power level between nodes was set to 3 dBm for all experiments, the maximum transmission power level available. The message interval was set to 250 ms. According to the 802.15.4 standard, each received packet provides the LQI value which measures the correlation of at least two symbols of the PSDU (Physical PHY Service Data Unit frame) of the packet. LQI values are integers between 0 (minimum) and 255 (maximum). These values must be associated with the lowest and highest signal quality, respectively. As stated by the IEEE standard 802.15.4 [13],LQI values provided are uniformly distributed between these two limits. The radio transceiver [15] determines the link quality of a radio link using correlation results of multiple symbols within a frame to determine the LQI value. The minimum frame length for a valid LQI value is two octets PSDU. The LQI values can be associated with an expected PER which is the ratio of erroneous received frames to the total number of received frames. A PER of zero indicates no frame error, whereas at a PER of one indicates no frame was received correctly. Our experiments were designed based on the works [17] and [18], which define an experimental methodology for wireless networks.

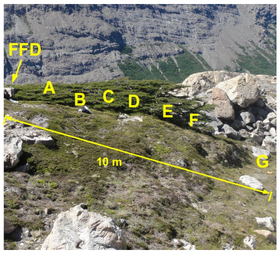
B. Test Scenarios Description

The experimental scenarios and the testing locations were chosen based on the the area where the IANIGLA researchers keep the study of the Lenga seedling. The scenarios covered are: 1) treeline zone: Lenga Floor - 100 mts. from Ana Glacier, 2) treeline zone: Fix Point called TOR 4, 3) Toro Glacier Moraines and 4) Leafy Forest Area.

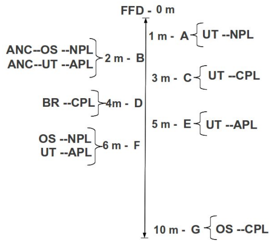
1) Treeline Zone near Ana Glacier: In this scenario we studied connectivity over a 10mts length area located over the treeline zone with coordinates S 49º 4' 15.36" W 72º 58' 8.20", as shown in Fig. 1a. As described schematically in Fig. 1b, in all measurements of this scenario the FFD was located on a fixed position over rock of about 70 cm high, and the RFD was positioned on different locations and in different positions relative to a rock. [1]

[1]List of acronyms definitions used in the paper (eg. in Fig.1b,2b):

- Related to the Position of RFD: OS:On Soil, OR:over rock,BR: behind rock,UR: under rock,BT:behind tree,UT: under tree
- Related to the conectivity : NPL:no packet loss, CPL connectivity with packet loss, APL: all packet lost,
- Related to the Antenna's position of RFD: ANC: no pointing to FFD. By default the RFD is always pointing to FFD



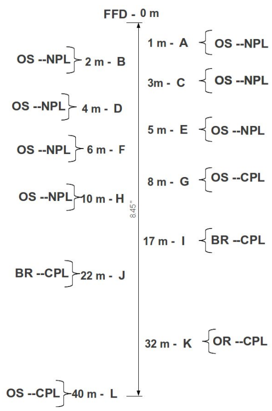
(a) Picture of the treeline Zone



(b) Results [1]

Fig. 1: FFD and RFD Position in the Ana Glacier

(a) Picture of the treeline Zone TOR4



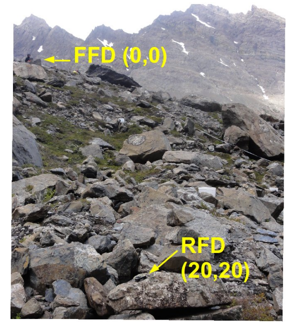
(b) Results. [1]

Fig. 2: FFD and RFD Position in TOR4

2) Treeline Zone, Fix Point called TOR 4: This scenario was also located over the treeline zone, in a linear zone spanning 40m over coordinates S 49º 4' 16.25" W 72º 58' 4.10" (Fig. 2a). In all measurements the FFD was positioned over a rock of about 30 cm high, and the RFD was located on different measurement points (Fig. 2b).

3) Moraines of Toro Glacier: This scenario measured connectivity over the Moraines of Toro Glacier (Fig. 3a), over coordinates S 49º 3' 30.19" W 72º 58' 3.69". A coordinate axis was set (x=[0,20]; y=[0,20]), the FFD was fixed in (0,0) over a rock 10cm high and the RFD was moved through different positions. The positions list and the respective results are the following [1] : (0,2) UR-NPL, (0,5) OR-NPL, (0,10) BR-CPL, (0,16) BR-APL, (0,20) OS-APL, (20,20)OR-NPL,(20,10) UR-APL, (20,0) OR-CPL.

4) Leafy Forest Area: Finally, we present a scenario in a Lenga wood (Fig.4a) located at coordinates S 49º 3' 49.39" W 72º 57' 28.04". A coordinate axis was set (x=[0,20]; y=[0,20]) where the FFD was located at 1.20 m high in (0,0) and the RFD were located on different measurement points at 1.20 m high. The RFD's positions list and the respective results are the following [1] : (7.4,4) NPL , (7.8,6) NPL, (0,20) NPL , (0,20) ANC - CPL , (20,20) APL , (10,10) NPL , (10,10) ANC -NPL, (10,7) CPL , (20,0) NPL , (20,0) ANC - APL.



(a) Moraines

Fig. 3: FFD and RFD Position in Moraines of Toro Glacier

(a) Forest zone

Fig. 4: FFD and RFD Position in Leafy Forest Area

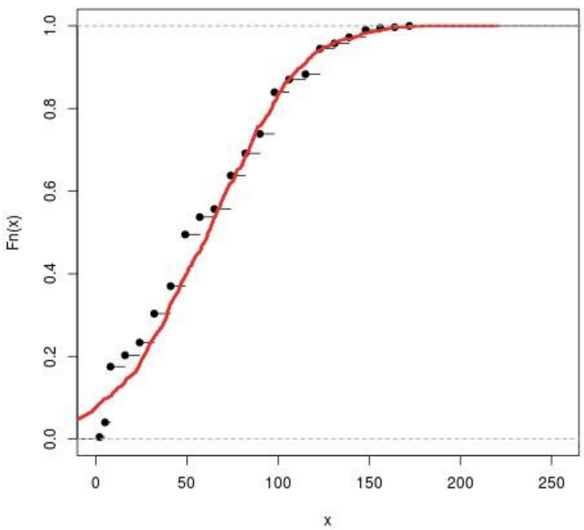
VI. RESULTS

Measurements of each scenario were fitted to a Gaussian distribution $G(\mu, \sigma)$ using maximum-likelihood method where μ is the mean value and σ the standard deviation (Table I). The cumulative distribution function (CDF), given by $F(x) = \int_{-\infty}^{x} f(u)du.$, was used to interpreted the results in order to get the probability that LQI values will be found at a value less than or equal to x. A good fit would allow future estimation of LQI for different scenarios relevant to the IANIGLA researchers, and the consequent deployment of WSN in these scenarios.

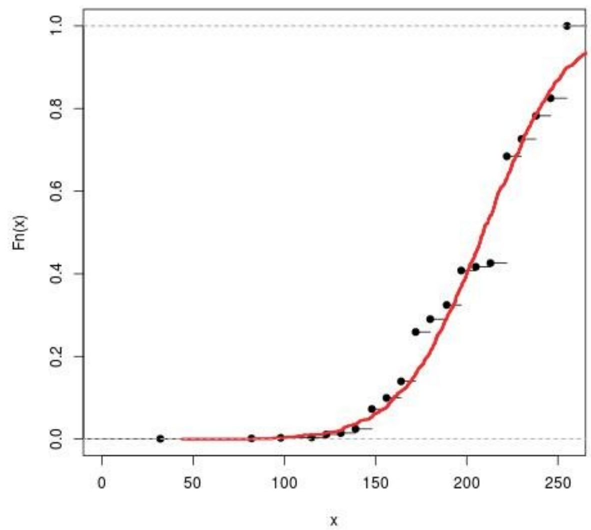
TABLE I: Parameters fit for a Gaussian for each near zone

	Treeline Zone Ana Glacier	Treeline Zone (TOR4)	Toro Glacier Moraines	Leafy Forest Area
μ	62.02	209.23	67.34	128.24
σ	40.62	35.76	59.38	82.29

We first analyze the different LQI distributions which characterize each environment. A simple calculation from the results on Fig.5a shows that 90% of the measurements are below an LQI of 125 on Lenga Floor zone, while on Fig. 5b, the same percentage of measurements are above LQI of 250. This is due to the different vegetation conditions: one the first case, measurements are executed on the limit between vegetation and free soil, while on the second, a thin layer of dense vegetation covers the full path. On Fig. 5c we can observe a deviation from a Gaussian fit, probably due to the shadowing of small rocky cliffs. Nevertheless, the distributions



(a)



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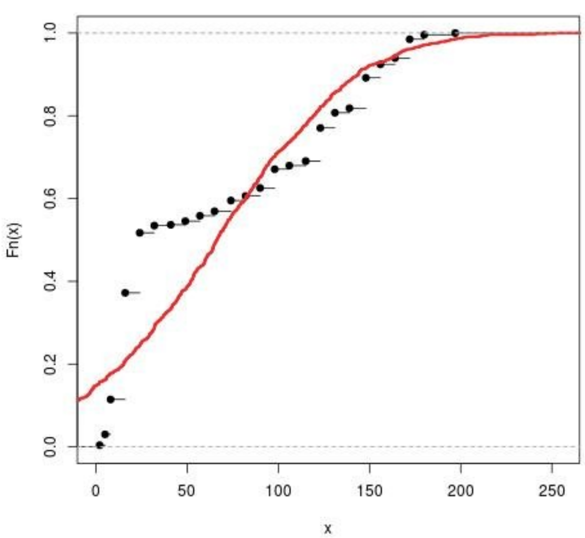
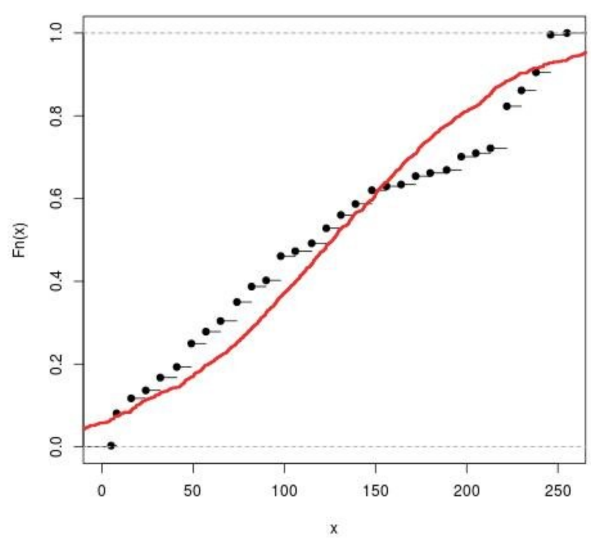


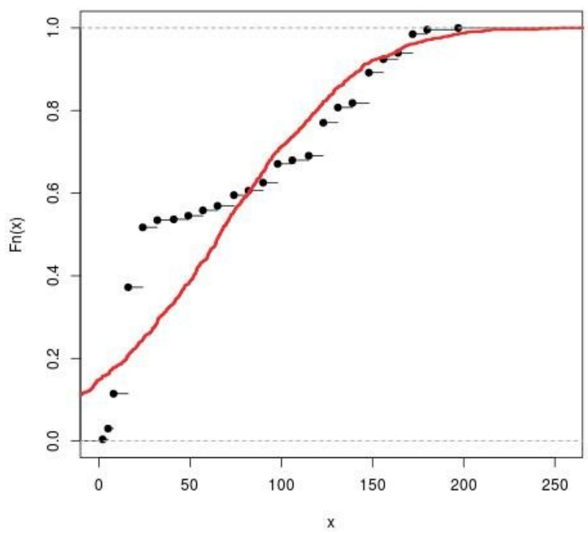
(c)



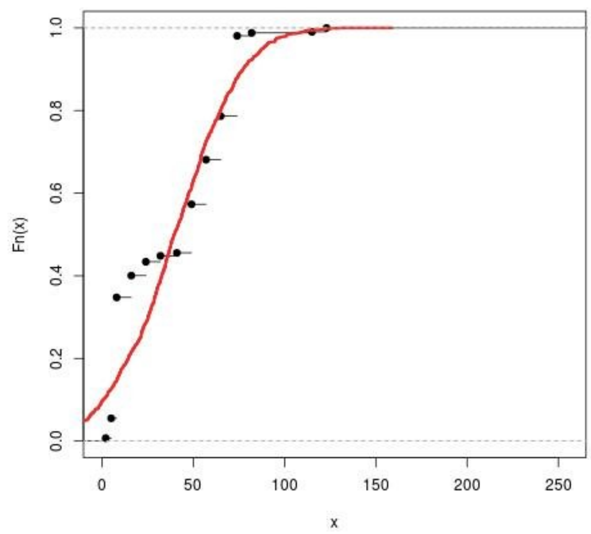
(d)

Fig. 5: Empirical cumulative distribution function (Fn(x)) over LQI values in different near zones: 5a) Treeline zone near Glacier Ana, 5b) TOR4, 5c) Toro Zone and 5d) Leafy Forest. On x-axis shows LQI values ranged from 0-255.

are similar, but Toro Moraine is shifted to the right. Finally, on Fig. 5d the forest scenario shows a flatter CDF centered on LQI of 125, given absence of wide area shadowing elements, such as the large rocks found on Toro Moraine (Fig. 5c). The almost linear CDF represents the consequences of a large number of consecutive shadowing, reflection and refraction effects. We now analyze the effect of distance on the distribution of LQI values for three different groups: Near, Middle and Far for each scenario. The results for the Toro Moraine scenario are shown on Fig. 6 whose results we proceed to analyze. Apart from the deviation from the Gaussian fit we have mentioned on the former paragraph, the three CDFs show an increasing steepness with distance together with a decreasing median value. The successive effect of ground-level and reflection on the surface of rocks is more evident on the Near case: reflected power is still significant to affect the LQI value. Reflections are mostly attenuated with distance, so their effect is further reduced in the Middle and Far groups. Vegetation is absent in this scenario, and rocks are opaque to Radio Frequency. As a consequence, attenuation is only due to distance in this case.



(a)



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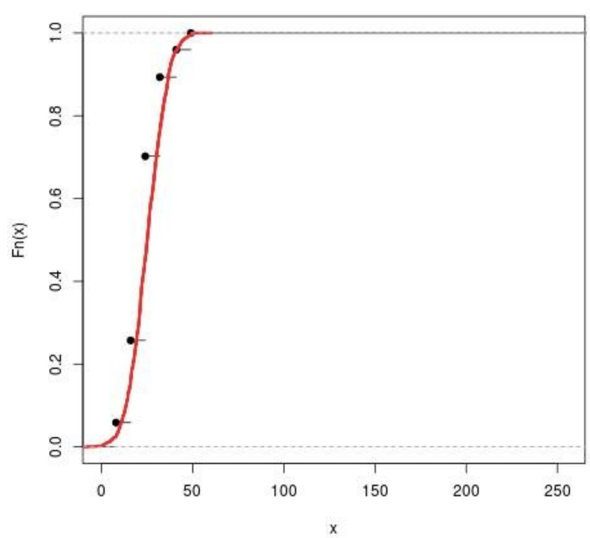

(c)

Fig. 6: Empirical cumulative distribution function in Toro Moraine scenario: 6a) Near, 6b) Middle and 6c) Far

VII. Conclusions and future work

Our work summarizes the behavior of LQI in specific outdoor scenarios in El Chaltén, Santa Cruz province, Argentina. To achieve a better LQI-distance behavior understanding, we divide each scenario in three groups: near, middle and far. We summarize the LQI results in probabilistic distributions for each region which characterize the measurement variations. Thanks to the results obtained, the expected behavior of Packet Error Rate can be estimated, from the empirical model of LQI measurements, providing a relevant source of information for future WSN deployments in the area.

VIII. Acknowledgements

This study was partially supported by Anillo Project ACT-53, Fondecyt project No. 11121475, CIRIC (INRIA-Chile) Project "Network Design", Project Semilla - UDP "ANDES" and "Análisis y diseño de algoritmos en redes de bajo consumo aplicado a condiciones extremas de los Andes": Programa de Cooperación Científica Internacional CONICYT/MINCYT 2011 and by Inter-American Institute for Global Change Research (Grant CRN2047B). The instruments needed to execute the experiments were provided by GridTICs [19] from Project PICT2010-22 "RED SIPIA - Red de Sensores inalámbricos para investigación Agronómica". Facundo Bromberg is financially supported by Universidad Tecnológica Nacional and CONICET, Argentina. Ana Diedrichs thanks her doctoral fellowship granted by Universidad Tecnológica Nacional. Finally, the authors are thankful with IANIGLA team for their support during the Campaign in January 2012.

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