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Field performance analysis of IEEE 802.15.4 XBee for open field and urban environment applications in Smart Districts

Pawel Rycerski^{a*}, Luis M. Candanedo Ibarra^a, Fivos Galatoulas^a, Konstantinos N. Genikomsakis, Ali Bagheri^a, Christos. S.Ioakimidis^a

^a ERA Chair (*Holder) 'Net-Zero Energy Efficiency on City Districts, NZED' Unit, Research Institute for Energy, University of Mons, 56 Rue de l'Epargne, 7000, Mons, Belgium

Abstract

This paper analyses the performance of the Xbee-PRO IEEE 802.15.4 (ZigBee protocol) based Wireless Area Network transmission component for urban environment, as part of the Smart City concept. This embedded solution was designed to provide a wireless networking layer for Machine-2-Machine (M2M) communication. A series of carefully designed field comparison tests in a “0” obstruction environment and a real urban area was conducted using three-dimensional positioned nodes. The objective of the study was to simulate the potential applications and expose the cases where this technology cannot be applied. The obtained results reveal significant deviation from the technical manufacturer specifications when applied in the actual field measurement environment.

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1. Introduction

The realization of the Smart Grid paradigm as part of the Smart Cities concept requires the collection and analysis of real-time data, along with the control of electrical loads for energy reduction and demand response,

* Pawel Rycerski. Tel.: +32-653-744-57 ; fax: +32-65-37-44-00 .

E-mail address: pawel.rycerski@umons.ac.be

emphasizing the importance of the communication infrastructures required to support control and data exchange between the various domains which comprise the smart grid. In this context, the ZigBee protocol was developed for standardized application software on top of the IEEE 802.15.4 wireless standard. The U.S. National Institute for Standards and Technology (NIST) has defined ZigBee and the ZigBee Smart Energy Profile (SEP) as one of the communication standards for use in the customer premise network domain of the smart grid. ZigBee wireless technology is characterized by low cost, low power, low data rate, and simplicity [1]. These features, along with its operating over an unlicensed spectrum (not the same in all countries) and being a standardized protocol based on IEEE 802.15.4 standards, facilitate easy network deployment and implementation, and make it a promising wireless technology for smart grid applications. More specifically, the XBee RF ZigBee based module is one of the commercially available wireless transceiver solutions that utilizes a fully implemented protocol for data communications and gathers features that ensure safe delivery of data across nodes in various configurations. The XBee can substitute one XBee for another, depending upon dynamic application needs, with minimal development, reduced risk and shorter time. XBee 802.15.4 RF modules are ideal for applications requiring low latency, predictable communication timing over small distances.

In the framework of the present work, a series of carefully designed field comparison tests in zero (0) obstruction environment and urban area was conducted using three dimensional (3-D) static and dynamic positioned nodes. Performance of the study has as an objective to simulate potential applications in the Smart City and Internet of Things (IoT) domain. It consists in analyzing both radio performances in function of natural urban environment obstructions versus manufacturer specifications. The results of this paper provide an idea of potential uses for distinctive M2M communication in upcoming Internet of Things (IoT) applications in the Smart Cities domain.

However, operating on the license-free industrial, scientific, and medical (ISM) frequency band, ZigBee is subject to interference from various devices that also share this license-free frequency band, ranging from IEEE 802.11 wireless local area networks (WLANs), WiFi networks, lower GSM bands, Bluetooth, to baby monitors and microwave ovens, resulting in severe performance degradation. Studies have shown that WiFi is the most significant interference source for ZigBee within the 2.4 GHz ISM band [2]. This paper does not concentrate on a particular application, but rather gives an overview of performance of this technology and facilitates the design of hypothetical network implementations.

2. Design of field tests

Conducted experiments were designed having in mind the impact of main technical specifications and potential application in real urban environment. This study considers key factors that can be found in possible use cases, including different heights of placement of two nodes put to communicate one with the other as well as the fact of having one of them on the move, here and afterwards referred as a dynamic test. For this purpose three sites with different obstruction levels were selected, namely minimum (open field), medium (residential area), and maximum (old-town). All tests were conducted with two nodes, where one was serving as *transmitter* and the other as *receiver/repeater*. The only difference between them is that the transmitter was static in place, next to the hardware harvesting the data and the receiver's distance was modified as the test progressed. Both were powered by external 5V 1A power source (via 0,5m cable in length). In this paper, we have considered the XBee PRO S3B 900HP device (Through-Hole model board) from Digi International to perform all tests. The radio module can operate in the range of 902 to 928 MHz, which makes it FCC and ISM certified and was used in conjunction with antenna mounted directly on the module board. The XBee-PRO 900HP specifications claims the LoS (Line of Sight) range up to 6.5km @ 200kbps and up to 15.5km with 10kbps transfer speed and up to 610m and 305m in an urban environment (with adequate data rate respectively), all of which also requires dipole, dedicated antenna. In our case, we are using more common 6 inch, 1W, 200mm omnidirectional (1/2 Wave Dipole Articulated) antenna with 2.1 dBi gain and RPSMA connection. The module transmit current is 215 mA, and the transmit power was set to 250mW @ 24 dBm (the configuration permits 4 levels of power transmission). Transition speed was 10 kilobits per second by default.

2.1. Open field

The site consists of a newly developed technology/industrial park with just one building under construction in a range of 500m from the point of taking measurements. There were no overhead cable installations. Existence of underground installations like high power supply or similar that might influence in any matter the readings are not known. All wireless communication channels on the computer carrying out the test were shut down for the duration of the measurements. This test was performed in order to see how the device acts in near 0 obstacles conditions and compare them afterwards to common urban behavior.

2.2. Urban area

The environment of this test was chosen due to topology, mostly terraced buildings featuring some semi-detached houses and few blocks of flats – an area with potential to be converted to Smart District [3]. Tests were conducted in two main stages which each one of them had its static and dynamic phase.

2.2.1. Old Town

The test was conducted near the heart of the city's old town (Mons, Belgium). The site was selected for maximal possible signal distribution over space. This particular location is located on top of a 3%, highly urbanized grade hill. A majority of the buildings consist of two-storey brick houses with habitable rooftops (reaching average height of 12m). The construction dates to the XVI century and was mostly renovated or refurbished during the XX century. The streets in this area are twisted and narrow. On the top of the hill, there is also a second more elevated part (by 15m) with restored fortification walls and the upper part of town's main clock tower. The test runs were conducted in same scheme as the tests in the urban area.

2.2.2. Residential area

The tests were conducted in two phases: with a transmitter located in the middle of roundabout (antenna height position: 2m) and on a residential block of flats (antenna height: 5m, distance from the face of the building 0,5m), as seen in (Fig. 1a-b). Both tests were conducted with a static and a dynamic receiver. The dynamic test was performed with an specially adapted bicycle (Fig. 1c), featuring Xbee node with antenna (on telescopic arm) and a portable personal computer for Real Time (RT) storage and analysis of data. This type of area is known for having the sides of streets heavily occupied by resident's passenger cars, which strongly influence the propagation of the radio signal.

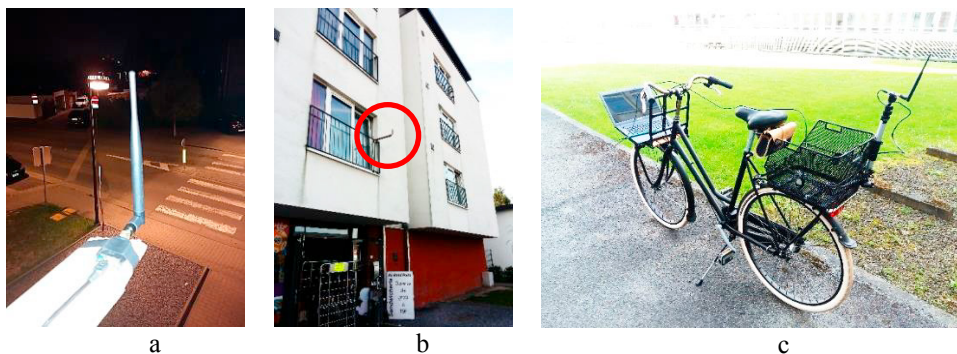


Fig. 1 Residential area setup

3. Experimental results & discussion

3.1. Open field

The measurements were taken within three dimensions, varying direction and height – both of the transmitter and the receiver (Fig. 2a). It has been found that there is a relationship between the two heights, achieving the best results maintaining one node at a height of 2m while the other at 3m (Fig 2b).

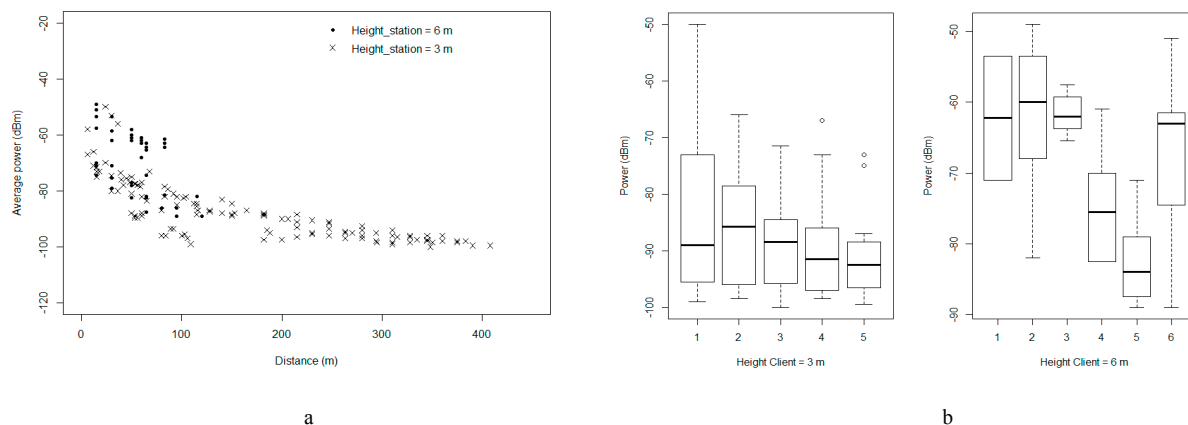


Fig. 2 Impact of receiver height on transmission distance and quality

What was interesting to find is the fact that having both transmitters at equal heights produced good results but modifying this relation just by 1m had a considerable impact (Fig. 2a). Also having one of the transmitters at 3m and varying the other produced much more predictive results (Fig 2b). The polynomial regression function achieved for this case is presented (1).

$$Av. dBm = -6.431e^1 - 3.392e^{-1}Distance + 1.325e^{-3}Distance^2 - 1.782e^{-6}Distance^3 \quad (1)$$

There has also been observed and registered a difference in signal strength as a function of the distance of nodes, which is fairly consistent and is expressed in formula (2) and Table 1.

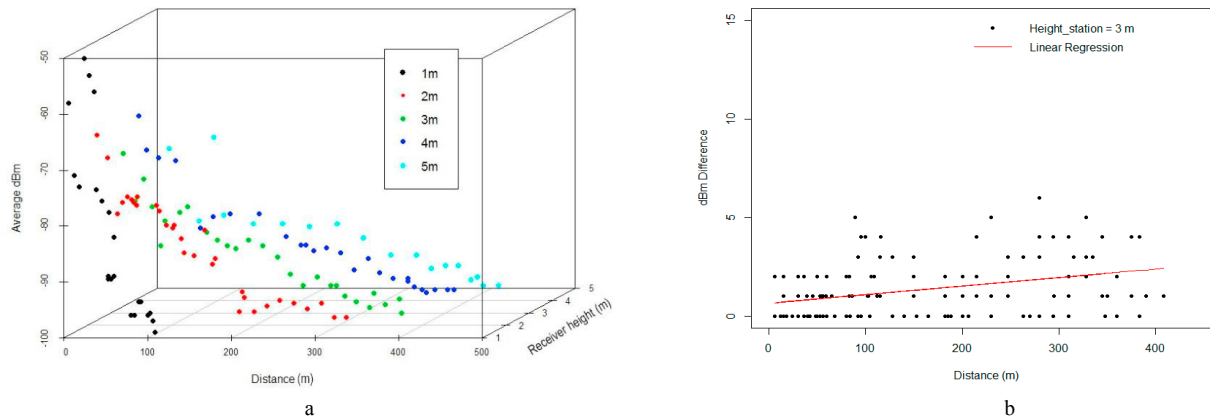


Fig. 3 a) Influence of height and b) nodes signal average difference with linear regression for static node on 3m

$$dBm_{diff} = 0.647387 + 0.004327Distance \quad (2)$$

Table 1 Coefficients and Statistics for dBm_difference

	Estimate	Std. Error	t value	Pr(> t)
Intercept	0.647387	0.215889	2.999	0.00328 **
Distance	0.004327	0.001059	4.087	7.79e-5 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-squared: 0.1187, Adjusted R-squared: 0.1116

3.2. Urban area

The urban and residential tests were executed with low traffic rate, medium temperature of 15 degree Celsius and average humidity of 65%.

3.2.1. Old Town

The results in the old town provided very limited results permitting the transmission only in LoF, up to the face of first line of buildings. Whenever the direct azimuth path between the two modules was interrupted by a building, the signal strength was dropping considerably with the rate of 5dBm every 3m (from the best achieved -85dBm). The height of the receiver did not produce any difference either (ranging from 6 to 1 meter).

3.2.2. Urban/Residential area

All the measurements with registered static nodes were converted into heat map, illustrating the propagation and loss of signal due to not only the topology of the sites with all the major obstacles (buildings) but also accumulated impact of trees, lamppost, signposts and parked cars as seen in Fig. 4a-b.

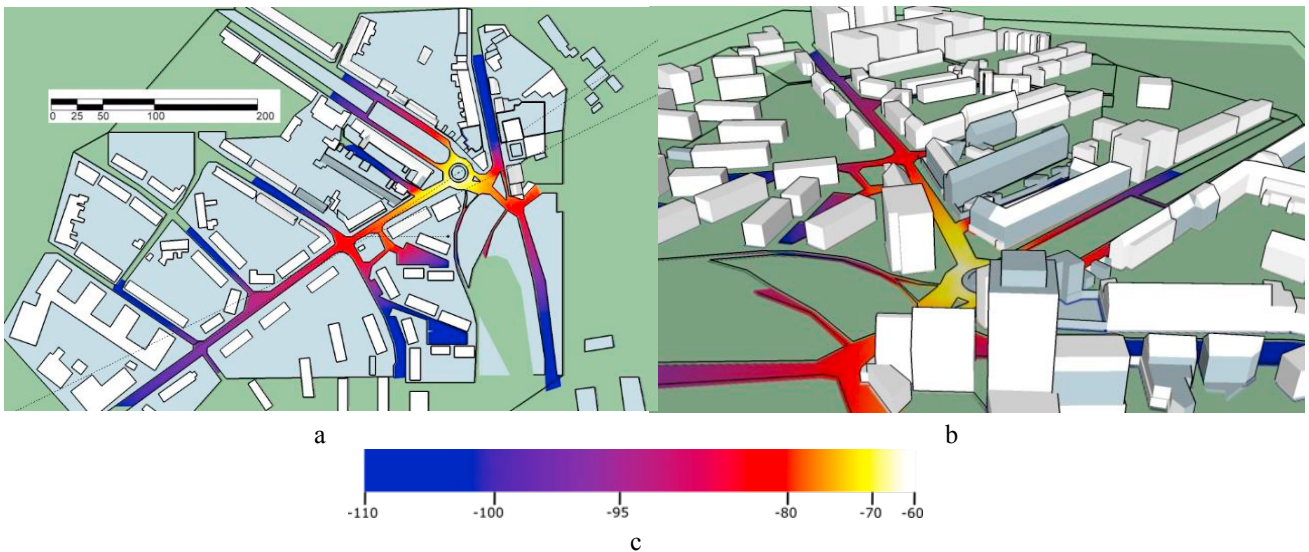
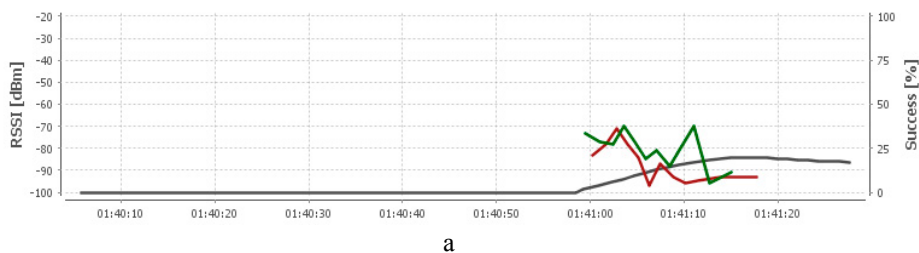


Fig. 4 Heat map of signal propagation and loss (static test) a) 2D – scale in meters b) 3D perspective view c) gradient value scale in dBm

It can be observed that in the narrower street the signal loss propagates much more even and permits the connection over a much longer distance compared to the street divided by the area of green space and ~50% of occupied parking lot.

Fig. 5 plots the results of dynamic tests. The nature of this test consisted of showing the quality of the signal, time of reconnection and stability of nodes while approaching the transmitter (maintaining constant speed, 15 – Fig. 5a and 30 km/h – Fig. 5b) with the receiver. The plots represents the entire transmission from the point of start (400m distance between nodes) up to 200m passing the *rendezvous* point.



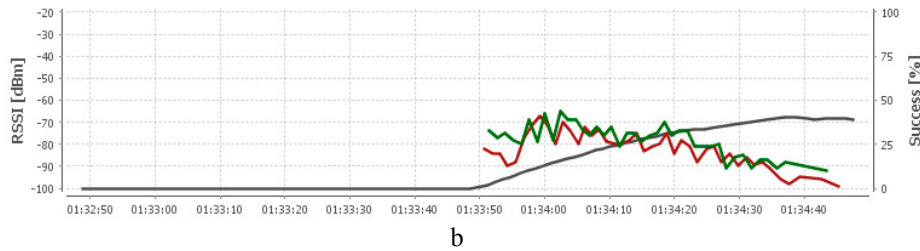


Fig. 5 Re-connection time and signal strength comparison at 15 and 30 km/h

That (Fig. 5) demonstrates the poor ability of this model of Xbee to reconnect to its assigned topology on the move, with speeds as low as those achieved by slow moving vehicle like a bicycle or running person. In both cases (Fig. 5), in order to assure the data transmission, one node needs to come in a LoS distance not greater than 50m from the other node.

3.3. Other observations

During the period of tests and trials there were observed phenomena of general higher correlation between the signal strength of both of the modules while communicating as a function of distance. While the distance in the urban area was kept below 50m, the average correlation was reaching a factor of 0.91, while above 200m it was usually stabilizing at values of 0.82. On a distance of 180m the signal difference can vary by -10dBm as a function as f.i. of a close or passing object like a small car that is in the way of LoS.

4. Conclusions

The Xbee modules in the performed test showed extremely high sensitivity of the signal to any obstruction in direct line of sight. Not only cars cutting the LoS path but also dense trees, road poles and road illumination poles can significantly reduce the transmission distance or directly interrupt the transmission forcing reconnection. It has been shown that there is consistent and considerable difference in signal quality, while varying the heights of nodes.

As it turns out, there is an important deviation from the technical manufacturer specification when applied in an actual field measurement environment. Particularly, (found during this research) the ability of signal propagation through an urbanized area makes the application of this standard less likely to be used in future outdoor urban applications, especially those where nodes are required to displace and reconnect dynamically one to another.

Acknowledgments

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