Using RSSI value for distance estimation in Wireless sensor networks based on ZigBee

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Abstract – In today's modern wireless ZigBee-based modules, there are two well-known values for link quality estimation: RSSI (received signal strength indicator) and LQI (link quality indicator). In respect to wireless channel models, received power should be a function of distance. From this aspect, we believed that RSSI can be used for evaluating distances between nodes. The experiment described in this paper indicates that RSSI is, in fact, a poor distance estimator when using wireless sensor networks in buildings.
Reflection, scattering and other physical properties have an extreme impact on RSSI measurement and so we can conclude: RSSI is a bad distance estimator.

1. INTRODUCTION

Wireless communication has become a very popular research topic, over the last decade. Ah-hoc networks and their derivate – Wireless sensor network (WSN) have become interesting research fields, with the advent of cheaper and smaller radio modules, and microcomputers. There are many active applications where WSN can be used: From military applications to healthcare and environment-monitoring [1].

There are many research fields in WSN but they can mainly be categorized as: research into physical layers (channel and radio research), MAC layers (optimal energy saving MAC protocols), and upper layers (topology, routing, QoS…) research.

There are many communication technologies connected with WSN. One of the most promising is the so-called ZigBee [2]. ZigBee is a 2.4 GHz-based low power, low data rate (up to 250 kBps) wireless technology.

Many vendors offer us a ZigBee stack with their ZigBee solutions. No matter the vendor, working with a ZigBee stack still requires high programming skills and deep ZigBee theoretical knowledge.

When deploying a wireless sensor network (with some scenario exceptions) we must have in mind that every node has a limited amount of energy. How to optimally preserve energy is one of the major research topics concerning WSN research.

There are many ways to preserve energy but one of the most common ways is to optimize radio transmitting power, idle-state and sleep-state.

Topology control primary defines those links used by routing algorithm and topology control links are defined by radio transmitting power. In other words: if we want to optimize radio transmitting power we must know link behavioral characteristics. We approached the link behavior characteristic by assuming that radios are omnidirectional when transmitting.

After characteristic simplification, we tried to find any correlation between radio link quality and distance, and to describe it using RSSI and LQI variables. We used MRF24J40, CC2420 and ZENA modules to compare and evaluate the measurements.

2. WIRELESS CHANNEL MODELS, RSSI and LQI

There are many radio propagation models known for wireless communications that predict signal-strength loss with distance - path loss. There are three models widely used for wireless sensor networks:

- **Free space propagation model** is built on the assumption that the transmitter and receiver are in the line of sight, and there are no obstacles between them. A simplified model can be defined as:

$$P_r(d) = C_f \frac{P_t}{d^2}$$

Where P_r is the received power, C_f constant depending on a transceiver, P_t transmitting power and d distance [3].

- **Two-Ray ground model** adds reflection to the previous model. A two-ray ground model receiver receives two rays: direct communication ray and reflected ray. A simplified model can be defined as:

$$P_r(d) = C_t \frac{P_t}{d^4}$$

The model can be simplified in this way if the distance d is much greater than the highness of the transceivers. C_t stands for the transceivers characteristics for the T-R ground model. Other variables have the same meaning as in the previous model [3].

- **Log-distance model** has been derived from analytical and empirical methods. It can simply be defined as:

$$P_r(d) \propto \frac{P_t}{d^\alpha}$$

Where α is the called distance-power gradient. There are tables defining α gradient and any interested reader can find it in [3].

These models are basically used in those simulations simulating WSN. When a practical approach is required there are two main variables measured when defining received-power and link-quality:

- **RSSI** stands for **Received Signal Strength Indicator**. It is the measured power of a received radio signal. It is implemented and widely-used in 802.11 standards. Received power can be calculated from RSSI.
- **LQI** stands for **Link Quality Indicator**. LQI estimates how easily the received signal can be modulated when considering noise in the channel.

For a better understanding let's give some practical examples of RSSI and LQI values:

- Weak signal and noise presence will give low RSSI and low LQI.
- Weak signal with noise absence will give low RSSI and high LQI.
- Strong signal and without noise gives high RSSI and high LQI.
- Strong signal in a noisy environment will return high RSSI and low LQI.
- And finally, strong noise my give high RSSI and low LQI.

3. TEST-BAY SETUP

Section 3 explains the setup procedures for the experiment.

3.1. Hardware setup

For test purposes, we used low-power RF modules MRF24J40 (replica of UZ2400 from Uniband Electronic Corp.) from Microchip, and CC2420 from Texas Instruments (previous Chipcon). All modules support the ZigBee stack. Beside RF modules we used wireless network analyzer ZENA produced by Microchip.

RF transceiver modules are controlled and interfaced with a microcontroller over SPI bus. For this purpose a PICDEM Z demo-kit was used. PICDEM Z includes microcontroller PIC18LF4620, and some other periphery.

The MRF24J40 is a 2.4GHz IEEE 802.15.4 transceiver supporting MiWi™ and ZigBee™ protocols. Other, custom-made protocols can be applied above PHY and MAC layers.

Wireless RF, PHY layer-baseband and MAC layer are integrated in MRF24J40. It can be used for many applications e.g. home automation, consumer electronics, PC peripherals, toys, industrial automation, and more. The radio chip is a very low-power device; typical current consumption is 18mA in the receive mode, 22mA in transmit-mode, and in sleep-mode 2µA.

The CC2420 is similar to MRF24J40 with some minimal differences. Both modules are purchased from Microchip. The first generation of ZigBee modules includes a CC2420 chip and the second includes MRF24J40. On the module there is a folded PCB antenna and an accessory for external 50Ohm antenna for achieving larger range communication. Only folded-antenna was used in our measurements.

The ZENA module uses a CC2420 chip for wireless networking analyzing. ZENA is connected to the PC via USB, which also powers the module. ZENA receives the packets on a specified channel and forwards it to the PC. With the hardware part of ZENA, software - user interface for PC is also included. User interface displays all the captured packets on a specified channel. We can store captured traffic to a file but the stored files can be analyzed only using ZENA software. Traffic information cannot be exported to text or similar file format. If someone wants to analyze data with another program, packets must be manually copied one by one to the text file.

Microchip offers demo examples for ZigBee and MiWi applications. These examples were used with some changes for our measurements. One ZigBee node sent a data packet and the other node received it. Each packet was handled on the receiving node. We extracted RSSI and LQI data byte from the received packet and sent them to the PC over RS232.

3.2. Test-bay preparation

We attempted to analyze correlations between RSSI value and distance. We used one fixed-node connected to a PC for data gathering and another 'mobile'-node. Both nodes were placed half a meter from the floor. Measurements were carried-out inside a long corridor (4m wide, 30m in length and 5m in height). The walls of the corridor were made of reinforced concrete. The distance between the sending and receiving nodes was carefully measured. No obstacles were placed in corridor.

During iterations, we moved the transmitting node over desired distances and took about 200 measurements. The distances were between zero and 25 meters.

Wireless internet (802.11b/g) networks were established whilst measuring. The wireless internet (802.11b) works on same frequency as ZigBee. So we could not predict any influence on measuring results.

Our measurements covered three different experiments:

- MRF24J40 module as receiver and transmitter
- CC2420 module as receiver and transmitter
- ZENA network analyzer as receiver, and CC2420 as transmitter.

The transmitting node was power supplied by a 9V a block battery. We changed the battery with new one for each new experiment. Thus, we eliminated any decrease of transmit-power.

4. VENDOR SUPPORT

After successful test-bay setup and node programming, we started to monitor data representing RSSI.

Firstly, we carried-out the experiment using the MRF24J40 module and boards. The downloaded stack and with the help of a datasheet, we found that RSSI is written as the last byte in an internal data packet, following the LQI byte [4].

We managed to read LQI byte and RSSI byte without any problems, but when calculating RSSI data byte to real RSSI value (dB), it became complicated. There are practically no instructions anywhere as to how to do is calculation [4].

After reading extensive of literature and datasheets, and analyzing ZENA values etc., we found a forum and used it when searching for the same answer. It led us to the conclusion that MRF24J40 is not a replica of a CC2420, as previously assumed but the replica of UZ2400 chip. After making this assumption, there has been no confirmation from the Microchip team about thus RSSI calculation to date and we are still simply assuming that our calculation of RSSI in correct.

Reading CC2420 datasheets is a totally different story. They clearly define where the RSSI data byte can be found [5].

Calculation is also clearly defined: Datasheets say that real RSSI is a 2's complement of the RSSI register.

Calculating real RSSI value offset must be added to the 2's complements' values:

P = RSSI_VAL + RSSI_OFFSET [dBm]

The ZENA module returns RSSI in a packet which is then displayed in the Zena module GUI.

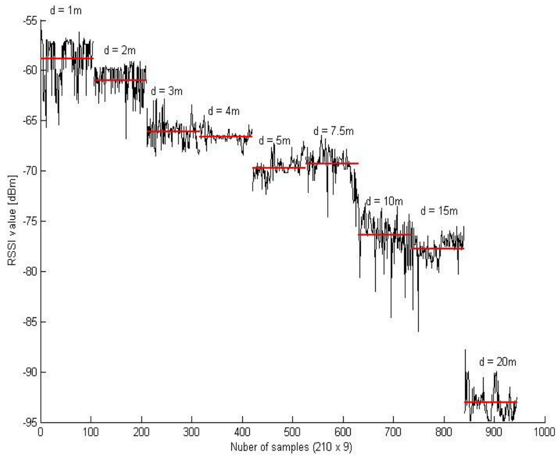

Fig. 3. Reading RSSI on MRF24J40.

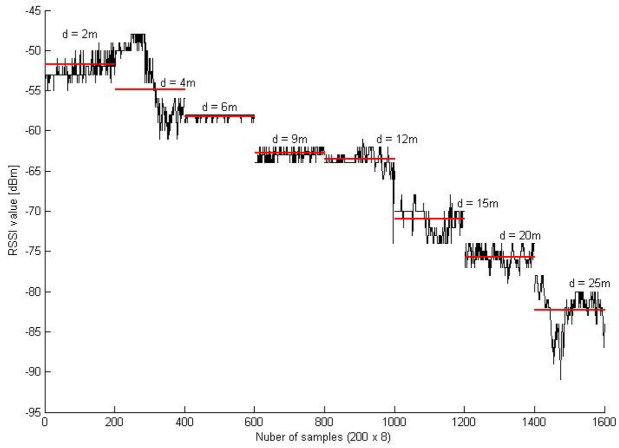

Fig. 4. Reading RSSI on CC2420

4. MEASUREMENT RESULTS

The first sets of measurements were carried-out using the MRF24J40 module. The firmware was changed as previously explained and within iteration (for every distance selected) approximately 270 measurements were done. From these 270 values we statistically (poison distribution) chose 210 values for representing the RSSI value. In Figure 3, a graph is shown for scattering every distance (1m, 2m, 3m, 4m, 5m, 7.5m, 10m, 15m and 20m). It can be seen that scattering is quite high. For that purpose we calculated the average value of the RSSI in dBm, and standard deviation "*(1)*" for every distance measured. We used standard formula for it.

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \qquad (1)$$

In Table 1 (MRF24J40), Table2 (CC2420) and Table 3 (ZENA) average values of the measurements can be found accompanied by the standard deviation.

Measurements were done in a real environment; not in a noise-free laboratory. This is because we wanted to place the modules within real working environment, in which they would normally be operating when deployed.

Distance	1m	2m	3m	4m	5m	7.5m	10m	15m	20m
RSSI	-58.889	-60.732	-66.086	-66.577	-69.6	-69.474	-76.439	-77.685	-93.141
St.Deviat.	2.233	1.407	1.313	0.632	1.035	1.621	2.024	1.453	1.408

Table 1: Distance, average RSSI [dBm] and standard deviation for MRF24J40 ZigBee module.

Distance	2m	4m	6m	9m	12m	15m	20m	25m
RSSI	-52.47	-53.35	-58.15	-63.17	-63.7	-70.27	-76.34	-82.89
St.Deviat.	1.091	4.186	0.309	0.480	0.367	0.848	0.649	2.206

Table 2: Distance, average RSSI [dBm] and standard deviation for CC2420 ZigBee module.

Distance	2m	4m	6m	9m	15m	20m
RSSI	-56.253	-65.461	-65.43	-69.615	-78.238	-85.169
St.Deviat.	0.682	1.579	1.295	1.267	2.682	3.33

Table 3: Distance, average RSSI [dBm] and standard deviation for ZENA ZigBee module.

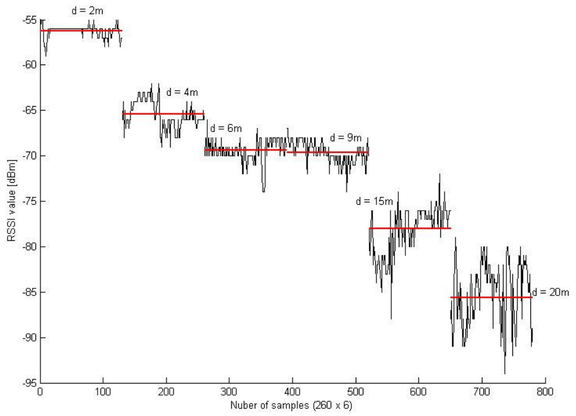

Fig. 5. Reading RSSI on ZENA.

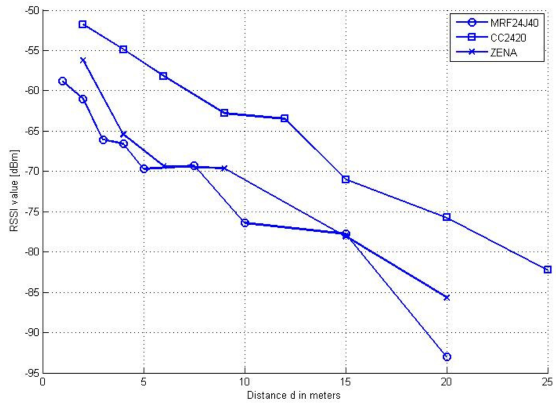

Fig. 6. RSSI vs. distance.

When we looked at any document regarding RSSI, we found tolerance from ±4 dBm to ±8dBm, which is quite high deviation for distance measurement.

There is a general belief that in Wireless sensor networks RSSI is a bad estimator of link quality. This belief was confirmed during our research.

On the other hand, there was research completed at Stanford University suggesting that RSSI could be a good estimator of link quality [7].

There was also LQI in question regardless of whether it defines link-quality. We tried evaluating the LQI factor on MRF24J40 module but it didn't change with the distance. It's value was between 102 to 122 regardless the noise level, distance, and other scenarios. The question is: does the LQI measurement inside MRF24J40 work as it should or not?

5. CONCLUSION

Before setting up this experiment, we strongly believed that RSSI would be good indicator of distance. Our expectations were supported by previous research [7], and the assumption that in the absence of external factors (water and moisture) RSSI values should not have high variations.

In regard to distance evaluation, as well as routing protocols, RSSI (or LQI) plays a significant role in deciding which link to use next (in multi-hop network) so that packet delivery will be optimal in time/energy matter.

The first problem come across was the problem of Microchip documentation and the interpretation of RSSI value. RSSI value is defined in datasheets but never explained as to how to calculate real RSSI value in dBm, in regard to the RSSI given by the MRF24J40 module (which is basically the AD value measured within the module).

When we had overcome the first problem we encountered the second one: Interpreting ZENA RSSI value. When working with ZENA there are two possibilities for data interpretation on the GUI. When using verbose interpretation it seems that Microchip forgot to subtract referenced value (suggested by ChipCon: -45dBm).

When working on data manipulation, we got the feeling that both the CC2420 and MRF2420 reading values were practically equaled well. All the measurements were within the tolerance values ($\pm$ 8dBm).

In the end, the question arises as to where these values are precise enough for distance evaluation? We believe that the answer lies in their application namely: how precise the distance evaluation must be. Of course when exchanging enough packets the distance can be precisely evaluated if the terrain variables and conditions are near 'perfect'.

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