Wireless Sensor Network Simulators Relevance compared to a real IEEE 802.15.4 Testbed

Stéphane Lohier, Abderrazak Rachedi, Erwan Livolant, Ismail Salhi
Computer Science Laboratory (LIGM)
University of Paris-Est Marne-la-Vallée (UPEMLV)
Champs sur Marne, France
{lohier, rachedi, livolant, salhi}@univ-mlv.fr

Abstract—The diversity of research topics in Wireless Sensor Networks (WSNs) is attracting more and more researchers from different fields. The common point of all proposed solutions and protocols for WSNs is the evaluation usually done with the network simulators. In this paper, we focus on the results relevance of wireless sensor network simulators in two different scenarios based on indoor and outdoor environments. We propose a comparative study between 3 usual simulators (NS2, OPNET and QualNet) while using as reference a real testbed based on Imote2 sensor platform. Moreover, the impact of different MAC protocols (B-MAC and TKN15.4 MAC) which respect or do not observe the IEEE 802.15.4 standard are illustrated by real experimentations. These experimentations show that TKN15.4 protocol gives a better throughput than B-MAC. In addition, the results obtained from a comparative study between simulators show that 3 of them give different data even in the same environment. The NS2 simulator gives results close to those of the experimentation in the case of an outdoor environment, but in the indoor environment QualNet gives results closer to the reality.

Keywords: Wireless Sensor Networks, IEEE 802.15.4, Network Simulators, Testbed

I. INTRODUCTION

The design and implementation of new protocols or models for wireless sensor networks are mainly based on simulation in order to test and validate the proposed solutions. Simulations are indeed less costly and complex than a real implementation in testbed, especially if the density of the network and the complexity of the topology used are significant. Moreover, we are able to compare the performances of different protocols/models in different scenarios and through different periods much faster with simulations. When implementing a real world test (testbeds) like WPAN communication with ZigBee [1] devices, however, we have to take care of the type of environment, the terminal location and the parameters of the MAC sub-layer, because they may have an impact on the different protocols/models performances. To assess the relevance of a specific wireless network simulator, two questions must be answered: 1) Is the implementation of the lower layers (such as the physical layer) close to the reality/;enough realistic? 2) If the implementation is not enough realistic, how can we evaluate the relevance of our results, especially in the case of a dense multi-hop network, as we know that the transmission model between two nodes does not match a real situation?

Our involvement in such a study is thus due to three observations we made: 1) No work dealing with the latest 802.15.4 [1] devices ever reported any evaluation of their performance and respect of the IEEE standard. These studies focused on the different MAC 802.15.4 implementations (B-MAC, TinyOS 15.4 WG, TinyOS ZigBee WG, etc.) but we are not aware of any comparative study between the devices. 2) No work proposed a recent IEEE 802.15.4 comparative study between computations/measurements and simulations. 3) We plan to offer the researchers a guideline to help them choose and tune a simulator in accordance with the simulated environment.

This paper thus aims at:

1) assessing the performances of different MAC layers implemented in the latest 802.15.4 devices based on the CC2420 RF transceiver and checking their observance of the IEEE standard. The 802.15.4 devices performances are evaluated both in an indoor and in an outdoor environment. 2) estimating the relevance of the MAC 802.15.4 layer lately implemented in the different network simulators and comparing it to a real testbed. We will thus be able to provide researchers a guideline to help them choose and tune a 802.15.4 simulator in accordance with a specific environment.

To achieve these goals, we use two different scenarios: an outdoor free space and an indoor office. Two MAC protocols are investigated on: B-MAC (Berkeley MAC) [19] which does not observe the IEEE 802.15.4 standard and TKN15.4 MAC [18] which does. B-MAC protocol is a native protocol of many hardware devices like Crossbow sensors (MICAz, TelosB, Imote2). TKN15.4 MAC protocol includes almost the complete functionality described in the 802.15.4-2006 [2] specification, except for GTS allocation and management, security services, and a few minor services like PAN ID conflict notification. In addition, we focused on the transmission between two nodes and on three major network simulators: NS2 [14], OPNET [15] and QualNet [16]. In order to achieve these goals, we choose two scenarios (outdoor-free space and indoor-office) with a focus on the transmission between two nodes and three major network simulators: NS2, OPNET and QualNet.

This paper is divided into five sections. In section 2, we sum up the existing works dealing with experimentiation results and network simulators. We present an evaluation of B-MAC
and TKN15.4 MAC over Imote2 in section 3. Section 4 is dedicated to the major network simulators and the comparative study of their performances. The fifth section concludes our paper and presents the problematics we plan to deal with in our future works.

II. RELATED WORKS

Many works in literature deal with the performance evaluation of the IEEE 802.15.4 standard. These studies can be divided into three categories. In the first one [3-4], the results are obtained with real 802.15.4 devices. In the second one [5-7], they are obtained with different simulations. In the third one [8-10], the analysis and modelling of the 802.15.4 channel enable the network performances assessment. Petrova et al. [3] propose one of the most important studies dealing with real 802.15.4 devices. This study analyzes the performance of IEEE 802.15.4 through the measurement of the PER (Packet Error Rate) and the RSSI (Received Signal Strength Indicator) both in indoor and outdoor environments with only one emitter and one receiver. The RF transceiver usually uses the CC2420 from Chipcon [11]. The measurement shows that the PER is always lower than 0.5% for a distance up to 20m (3% up to 50m). These results demonstrate the OQPSK modulation efficiency compared to other schemes included in WiFi or Bluetooth technologies. The RSSI fluctuates between -7dBm and -45dBm on distances between 1m and 30m. In an outdoor environment, the transmitter can reach the receiver on a distance between 0 and 70m, with a RSSI close to -45dBm and a PER of 10%. These figures also show the OQPSK modulation very high energetic efficiency on long distances. However, no throughput measurement has been done in beaconed or non beaconed 802.15.4 modes [2].

The results are used to tune the error model in NS-2 simulator [14] for IEEE 802.15.4 MAC protocol, using IEEE 802.15.4 extension developed at the City College of New York [12]. In the scenario selected for NS-2, the number of transmitters fluctuates between 1 and 60 with a channel in the slotted CSMA-CA mode. The results show that the throughput is always lower than 45kbps (for a 250kbps nominal raw bit rate), however high the offered load and the number of sources. To put it in a nutshell, the beaconed mode is inefficient if a high throughput is needed. This mode should actually be used only if the offered load is low. As far as we know, no comparison between the simulator and the testbed throughputs has ever been carried out. Several studies comparing simulators and testbed have been proposed but they deal with IEEE 802.11 technology [20, 21, 22]. Recently, other works focused on the coexistence between both IEEE 802.11 and IEEE 802.15.4 technologies [23]. They demonstrate that when a 802.11b communication interferes with a 802.15.4 transmission, the central frequencies must be shifted by at least 7MHz to obtain a PER lower than 3%. On the opposite, the impact of the interference on 802.11b technology can be pointed out only when the offset between the central frequencies is of 2MHz.

The impact of the interference on IEEE 802.11g transmission is not noticeable, because of the robustness of the OFDM modulation used.

In a similar study [4], the authors have carried out several sets of practical experiments with an IEEE 802.15.4 compliant CC2420 transceiver [11]. The goal of this work is to study the performance of the direct and indirect data transmissions using the CSMA-CA mechanism with the beacon-enabled mode and to analyze the effects of the data payload size. This study shows that: (1) the data throughput is significantly reduced in the case of indirect transmissions (from 153kbps to 65 kbps for a 250kbps raw bit rate); (2) when the number of sources increases, both the effective data rate and delivery ratio decrease because of collisions and random backoffs; (3) the data rate increases according to the payload size but it has no significant influence on the delivery ratio; (4) the data rate increases according to the beacon order in the beacon-enabled mode (from 0 to 35 kbps) with a “beacon storm” effect in the case of a low order leading to very low data rates.

In [5], Lu et al. evaluate the performances of 802.15.4 MAC for the beacon-enabled mode, using NS-2 simulations. They found that an extremely low duty cycle operation enables significant energy savings but can lead to an important latency and a low bandwidth. The CSMA-CA algorithm reduces the energy costs but increases the number of collisions at a higher rate and with a larger number of sources. However, the use of GTS (Guaranteed Time Slots) can ensure a low latency but consumes the energy costs. Thus, it is difficult to find a trade-off, which mainly depends on the context and the type of application (real time, high throughput...). In this study, no guideline is proposed to tune the parameters of the simulator.

Zheng et al. present in [6] a complete simulation set using the Samsung/CUNY 802.15.4 implementation in an NS-2 simulator [15]. They carry out five sets of experiments, using the 802.15.4 PHY and MAC primitives. The goals of this work are: (1) to compare the performances between 802.15.4 and 802.11 technologies; (2) to study the association and tree formation; (3) to investigate on orphaning and coordinator relocation; (4) to analyze the unslotted CSMA-CA and slotted CSMA-CA behaviors; (5) to compare three different data transmissions, namely direct, indirect and GTS. This study shows that the 802.15.4 standard suffers from hidden terminal problems because of the absence of any RTS/CTS mechanism. However, for low data rates (up to one packet per second), the performance decrease is minor. The default CSMA-CA backoff period is too short, which leads to frequent repeated collisions. The superframes with low beacon orders (short duration between beacons) can also lower the slotted CSMA-CA backoff efficiency and lead to a high collision probability when the superframes are launched.

In [7], the authors have developed simulation tools for IEEE 802.15.4 slotted CSMA/CA mechanism using an OPNET simulator [16]. The sensor network is composed of a PAN coordinator and 100 nodes randomly spread in a 100m x 100m area. The basic conclusions are that the backoff algorithm is not flexible enough for large-scale sensor networks: the offered load (corresponding to the inter-arrival times of the flows in each node) should be around 50% to offer the best trade-off between throughput and average delay; lower superframe orders (active duration of the superframe) introduce additional overheads and thus limit the throughput.

The performance of the IEEE 802.15.4 contention access period is also analyzed in [8] in terms of throughput and energy consumption. For the analysis, the behavior of the nodes and
the channel are modeled, using Markov chains. For the lower layers, the authors used the characteristics of the CC2420 transceiver [11]. They show that the standard specified MAC can be accurately modeled as non-persistent CSMA. They also demonstrate that letting the radio in a shutdown state between the different transmissions is a very effective means of reducing the average power consumption for a very wide range of traffic rates. Finally, they propose to initialize the contention window length to 1, in order to significantly improve the throughput and reduce the energy consumption when MAC-level acknowledgements are not used.

Mische et al. have modeled in [9] the operation of the IEEE 802.15.4 MAC layer in the beacon-enabled mode through discrete time Markov chains. They identify the downlink queue stability at the PAN coordinator as the tightest criterion for the network. Consequently, they assume that the number of nodes and their traffic load should be chosen to avoid the saturation point of the network.

In [10], the authors provide an analytic performance model using Markov chains in order to compute the saturation throughput of the network in a star topology. The model is validated through simulations with NS2 in a network composed of a maximum of 50 nodes. One of the main conclusions is that the aggregated throughput is never higher than 70Kbps, whatever the number of nodes and the total load.

In this paper, we propose an original study consisting in evaluating several MAC protocols (BMAC and TKN15.4), using a real 802.15.4 testbed with two different environments (indoor and outdoor). We use the throughput, the RSSI and the loss ratio as evaluation metrics. The goal of this comparative study is to illustrate the impact of the MAC protocols which observe the IEEE 802.15.4 standard (such as TKN15.4) and those which do not (such as BMAC). The second contribution of this paper is to present and compare the results given by three major network simulators (NS2, OPNET, QualNet) with the testbed results. The added value of this contribution is to present and analyze the testbed and the simulation results in order to point out their divergences and the causes of these divergences.

III. EVALUATION OF B-MAC AND TKN15.4 OVER IMOTE2

A. Context

In this section, we point out the significant impact of the environment on the wireless communications. We distinguish two main environments: the indoor and outdoor environments. The indoor environment is more realistic, for instance the use of a wireless access in companies, offices and at home. The outdoor environment represents a free space area without any physical obstacle, such as emergency deployments. It is thus much less frequent, especially in a WPAN context. Nevertheless, many performance simulation studies on WPAN use the free space model, which is not very realistic. In the simulator, we can easily reproduce an outdoor environment, using a free space propagation model. However, this model does not take into account the floor reflection signals. On the opposite, the Two-ray ground model does consider these signals from a certain distance threshold between the transmitter and receiver nodes.

For our experiment, we selected scenarios taking place in two realistic environments. The first one is an indoor environment, represented by our laboratory, made up of 15-30m2 offices located along a 50m corridor. This scenario illustrates a usual office context. The nodes are located both in the corridor and an office, in order to take into account the fading effects. Nowadays, the WiFi technology is used in all buildings. Thus, we kept the existing WiFi communication on, in order to get results as close to the reality as possible (the 802.11 and 802.15.4 technologies use the same frequency band: 2.4 GHz). When the transmitter sensor wants to send a packet, it selects an available channel. The second one is an outdoor environment, also called free space. This environment is represented by our campus park without any obstacle. In both scenarios, we used one CBR connection with the maximum rate in order to reach the limit of the channel capacity (1KHz). The selected frame size is set to its maximum value (127 Bytes). The distance between the transmitter and receiver nodes fluctuates between 0 and 65m, which is its maximum value. Table I shows the default parameters of CC2420 technology.

<table>
<thead>
<tr>
<th>Frequency Band (ISM)</th>
<th>2400.0 – 2483.5 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>250 kb/s</td>
</tr>
<tr>
<td>Tx Power</td>
<td>-24 – 0 dBm</td>
</tr>
<tr>
<td>Rx Sensitivity</td>
<td>-94 dBm</td>
</tr>
<tr>
<td>Range (line of sight)</td>
<td>~30 m</td>
</tr>
</tbody>
</table>

For our experiment, we used the Crossbow sensor technology [13], particularly Imote2 sensors. These sensors are equipped with CC2420 radio transceiver [11], a 13-416MHz processor, a 256kB SRAM and a 32MB SDRAM. BMAC is the native MAC protocol in Imote2 sensors. We know that this protocol does not observe IEEE 802.15.4 standard and many capabilities are not implemented (such as the beacon-enabled mode). In order to compare the native BMAC protocol and other protocols which observe IEEE 802.15.4 standard, we have implemented and adapted TKN-15.4 MAC protocol to the Imote2 platform. The TKN-15.4 protocol is provided by the TinyOS 15.4 working group [17]. In this study, we only focus on the non-beacon-enabled mode, in order to provide a fair comparison between TKN-15.4 and BMAC. Indeed, BMAC protocol does not take into account the beacon-enabled mode. Table II shows the overhead attributed to BMAC and TKN-15.4 protocols.

<table>
<thead>
<tr>
<th>PHY</th>
<th>BMAC</th>
<th>TKN-15.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC</td>
<td>11 bytes</td>
<td>11 bytes</td>
</tr>
<tr>
<td>NWK</td>
<td>2 bytes</td>
<td>0 byte</td>
</tr>
<tr>
<td>DATA</td>
<td>113 bytes</td>
<td>113 bytes</td>
</tr>
</tbody>
</table>

The selected metrics for this study are the throughput, the RSSI (Received Signal Strength Indication) and the packet loss ratio in order to evaluate the performance of the transmission and the quality of the channel.
B. Results

The results related to the average throughput assessed at the receiver according to the different distances between the sender and the receiver are plotted in figure 1. Both scenarios (indoor-office and outdoor-free space) and the three MAC layers (BMAC TKN-15.4, and TKN-15.4 with ACK) are represented. Whatever the context, the TKN-15.4 MAC layer gives a better result than BMAC in terms of throughput. The TKN-15.4 enhances the throughput up to 50% compared to BMAC. This result reflects the different implementations of both MAC protocols in terms of buffer management policy and backoff algorithms. The obtained results show that the throughput reaches only 50% of the raw bit rate (250 kbps), except in the case of BMAC. In addition, we can compare the throughput provided by the same MAC layer (TKN-15.4) in both acknowledgement-enabled and non-acknowledgement enabled modes. This comparison shows that the acknowledgement-enabled mode is more reliable thanks to the retransmission mechanism, whereas the non-acknowledgement-enabled mode provides a 10% higher capacity. In the outdoor scenario (line of sight), the measured range is about the double (55m) of that obtained in an office environment (30m). Until this value, the throughput in the outdoor scenario is almost constant. This result demonstrates the robustness of the 802.15.4 channel. In the indoor scenario, the throughput may decrease by 20% until 30m. It decreases even more at a 25m distance, because of a geographical characteristic of the environment.

Figure 1. Throughput vs Distance (Indoor and Outdoor)

Figure 2 shows the evolution of the RSSI and throughput measured at the receiver according to the distance. In the case of the outdoor scenario, according to the mathematic formulation of free space environment, the signal level should decrease according to the distance square. The measured signal level is more versatile than expected. It depends on many parameters, such as the characteristics and orientation of the antennas, the floor reflections, the potential background noise, etc. In the case of the indoor environment, we expected a significant fluctuation of the signal level because of the number and nature of the dividing walls, the people moving in the area, the interferences with other transmissions, etc. The results show that the signal level is quite close to the one obtained in the outdoor scenario, which also demonstrates the robustness of the channel. What is the impact of the RSSI fluctuations on the throughput? Figure 2 shows that the throughput remains constant on short distances even if the signal level decreases. Then, the throughput significantly decreases on distances longer than 30m in the indoor scenario and longer than 55m in the outdoor environment. The 802.15.4 device thus tries to maintain a high data rate until a certain power threshold (approximately -40dB).

Figure 2. RSSI and Throughput vs Distance (Indoor and Outdoor)

The fluctuation of the packet loss ratio according to the distance is plotted in figure 3. The ratio is much higher for the BMAC in both contexts, which explains the differences in the measured throughputs (figure 1). The anomaly noticed at 25m is also illustrated in this figure. With the TKN-15.4 protocol, the loss rate remains very weak for ranges that are close to the limit. Even in the indoor environment, the rate remains lower than 10% until a 30m distance. Finally, the measured ratios enable us to give some guidelines for an IEEE 802.15.4 network deployment in both indoor and outdoor environments: the router mesh should have a 20m diameter in a noisy indoor environment and a 50m diameter in a free space environment.

Figure 3. Packet Loss Ratio vs Distance (Indoor and Outdoor)

IV. COMPARISON BETWEEN THE DIFFERENT SIMULATORS

A. NS2

NS-2 [14] is currently the most popular network simulator. We used the FreeSpace propagation models to simulate the outdoor environment and the Shadowing model with different parameters to simulate the indoor environment. In the latest versions of NS-2, the IEEE 802.15.4 extension developed at the City College of New York is included. Moreover, NS-2 observes the 802.15.4 standard and the frames are always acknowledged. The simulation parameters (frame size, CBR rate, data rate) are the same as those used for the testbed. The transmitted power is tuned in the free space model in order to obtain a 55m reception range. To be as close to the real testbed
as possible, neither the background noise nor the interferences are taken into account in the vicinity of the nodes.

For the Free Space model, the signal power alleviation is proportional to $1/d^2$:

$$P_r = \frac{P_t G_r G_t \lambda^2}{(4\pi d)^2 L}$$

$G_r$ and $G_t$ are the antenna gains, $\lambda$ the wavelength, $L$ the Loss Factor and $d$ the distance between two nodes. We tuned the values of Transmitted Power ($P_t$) and Capture Threshold ($P_r$) to obtain the same range as in the real testbed. These reference values are also used for the other propagation models.

For the shadowing model, two important parameters are used to differentiate the environment:

$$P_r(d) = P_r(\infty) e^{-\beta \log\left(\frac{d}{d_0}\right)} + X_{shd}$$

where $d_0$ is a reference distance, $\beta$ is the path loss exponent and is usually empirically determined by a field measurement. For instance, $\beta=2$ corresponds to a free space propagation. When we set $\beta$ to a larger value, that means that the number of obstructions is more significant, and the greater the distance, the faster the decrease of the received signal power. The second parameter $X_{shd}$ is a log-normal random variable which reflects the fluctuation of the received power at a certain distance. $X_{shd}$ is thus a Gaussian random variable with zero mean and a standard deviation $\sigma_{shd}$ which is called the shadowing deviation. $\sigma_{shd}$ is also obtained by measurement. For example, $\sigma_{shd} = 7\text{dB}$ corresponds to an obstructed office environment.

The comparative study of the testbed and the other simulators is plotted in figures 4 and 5. The testbed results are used as reference to compare the performances of the different simulators. First, we notice that the throughput obtained with NS-2 simulations is always higher, whatever the model. This is mainly due to the implementation of the 802.15.4 MAC layer. As for all simulators, the free space model gives a binary response: beyond a certain threshold, no more packet will be received. The shadowing model offers results closer to the reality but the parameters that drive the shadowing propagation are difficult to set. The documentation of NS-2 gives typical values of $\beta$ and $\sigma$ (for example: $\beta=2$ and $\sigma=4$ to $12\text{dB}$ for an outdoor free space environment; $\beta=4$ to $6$ and $\sigma=6.8\text{dB}$ for an indoor obstructed environment) but the shadowing model is probabilistic and insofar as these parameters have to be determined by field measurement, it is difficult to reflect the reality. Thus, it is possible to tune the parameters in order to obtain a curve close to the reality (indoor or outdoor) but these configurations cannot be generalized. In figure 5, for $\beta=2$ and $\sigma=4$, the throughput shows almost the same decrease as for the testbed in the indoor environment. However, according to the model, these parameters correspond to an “in building, line-of-sight” environment.

B. Qualnet

In order to carry out an efficient and fair comparison between the simulators, we used the same parameters as in NS-2. The proposed propagation models are close to those proposed in NS-2: free space and log-normal shadowing (in this model, only the deviation parameter is used). Qualnet also proposes the Rayleigh fading model, which occurs when there is no line of sight between the source and destination.

Figure 4 and 5 show the results of Qualnet simulations. The first remark is related to the average values of the throughputs which are lower than those obtained with the testbed or the other simulators (in the indoor and outdoor environments). Once again, the implementation of the MAC layer (backoff algorithm, clear channel assessment, MAC buffers...) has a significant impact on the performance. As for NS-2, the shadowing model gives better results for the indoor environment, despite a lower throughput. The shadowing deviation is tuned in order to obtain a curve close to the reality ($\sigma=4\text{dB}$) and the configuration is much more precise and effective than for NS.

C. OPNET

OPNET Modeler [16] is a network simulator well known in industry. The wireless suite of OPNET integrates 802.15.4 devices (PHY Extended Rate) and offers 5 propagation models intended for outdoor environments (Free Space, Longley-Rice, Hata, CCIR, Wallisch-Ikegami). OPNET Modeler views all wireless channels as Gaussian channels (uniform noise spectral density) and ignores the fading effect. In addition, OPNET uses a fixed value of the pathloss exponent without considering the diversity of the environments. Like for NS-2 and Qualnet the transmitted power is tuned in the free space model in order to obtain a $55\text{m}$ reception range. In that case, the obtained throughput is close to the reality.

The results for the free space model are plotted in figure 4. With the same power value, the other propagation models give very nearby results and are thus not represented. They are indeed designed for an outdoor environment and thus for transmission powers much higher than those usually used in IEEE 802.15.4 (greater than $100\text{mW}$) and for antennas with a range much higher than this present in the nodes (greater than $100\text{m}$). To conclude, although OPNET integrates 802.15.4 device and a lot of potential configurations (noise, loss factor, antenna models...), the propagation models proposed by default do not enable to carry out simulations close to the reality in an indoor environment (no result is plotted for that case in figure 5). It is necessary in this case to add other propagation models, such as the shadowing model. In addition, the beacon-enabled mode is not implemented.

![Figure 4. Throughput vs Distance Outdoor (Testbed compared to Simulators)](image-url)
In this work, we present a comparative study between MAC protocols which observe the IEEE 802.15.4 standard (such as TKN-15.4) and those which do not (such as BMAC). The impact of the different MAC protocols implementation in real testbed is presented and analyzed. In addition, a comparison between the results obtained from a real 802.15.4 testbed and three usual network simulators (NS-2, Qualnet and OPNET) is proposed. The main goals of this study are to test the performance of the real 802.15.4 MAC layers and to evaluate the relevance of the simulators, particularly in indoor and outdoor environments.

The 802.15.4 MAC layers implemented in the recent devices based on the CC2420 transceiver can be incomplete compared to the standard. The performances show that under a certain range threshold, the throughput in both indoor and outdoor contexts is relatively constant, which confirms the robustness of the 802.15.4 channel. The lower layers of the simulators are approximate, do not include realistic propagation models and give a throughput that is not realistic. Finally, despite difficult tuning of the propagation model parameters, NS-2 gives the results closest to reality in the indoor scenario, while Opnet gives the best results in the outdoor scenario.

In our future works, we plan to extend our study to the IEEE 802.15.4 with beacon-enabled mode. In addition, we consider improving the lower layers of the network simulators in order to generate results which are closer to the reality.

REFERENCES

[17] TinyOS 15.4 working group http://tinyos.stanford.edu/80015.4.WG