Radio Irregularity Obstacles-Aware Model for Wireless Sensor Networks

Tri Gia Nguyen[1, 2], Chakchai So-In[1] and Nhu Gia Nguyen[2]
[1]*Applied Network Technology (ANT) Laboratory,*
Department of Computer Science, Faculty of Science, Khon Kaen University, Thailand.
[2]*Duy Tan University, Danang, Vietnam.*
trigianguyen@kkumail.com and chakso@kku.ac.th

***Abstract*— Radio irregularity and signal attenuation are common phenomena in wireless sensor networks (WSNs) caused by many factors, such as the impact of environmental characteristics, the non-isotropic path losses, and especially, the obstacle on the transmission (multi) paths. The diversity of these phenomena make difficulty for accurate evaluation of WSNs' applications which specifically require high coverage and connectivity. Thus, in this paper, we investigated the radio irregularity and signal power attenuation, primarily due to the obstacle in WSNs. With empirical data obtained from experiments using a well-known sensor node,i.e., MICAz, we found that the signal strength attenuation is different in each case according to obstacle characteristics. Then, we proposed a radio model, called Radio Irregularity Obstacle-Aware Model (RIOAM). The results obtained from real measurements are also supported with regard to those from the simulation. Our model effectiveness is justified against a radio irregularity model (RIM) – higher precision with the existence of obstacles in WSNs.**

***Index Terms*— Obstacles; Radio irregularity; Radio model; Signal attenuation; Wireless sensor networks.**

I. INTRODUCTION

Connectivity in wireless sensor networks is always one of the most fundamental and challenging issues besides coverage, localization, routing, and quality of services. In most WSN applications, the (sensor) node deployment needs guaranteed connectivity to achieve effective monitoring [1-3]. However, with consideration of practical fields, with (multi) radio propagations, several irregularities and signals attenuation are norm, such as due to, obstacles, non-isotropic path losses, heterogeneous sending powers, and environmental factors [4]. These irregularities will lead to unpredictable and unreliable radio communications, called radio irregularity [5], which in fact, WSNs' applications become more sensitive to the irregularity of radio communication.

Traditionally, in most research on performance evaluation and analysis of WSN applications, researchers often perform experiments through computational simulations on software simulators, such as NS, Matlab, GloMoSim, TOSSIM, OPNET, OMNeT++, etc., instead of high-cost test beds [6]. For simplicity, some simulations of WSNs algorithms have been implemented along with an idealistic radio model where the radio communication is represented by a circular range. In addition, some researchers still simulate WSNs under theoretical radio models, such as two-ray [7] and free-space propagation model [8]. This has led to unrealistic results when using perfect circular range as a connectivity model, especially in the environment with the existence of obstacles. Hence, the design of a radio model taking into account the radio irregularity and signal attenuation due to the obstacle is necessary, and which is our focus.

In this paper, we intensively performed experiments to investigate the radio irregularity and signal attenuation behaviors using MICAz as a sensor node or mote in the environment that includes several kinds of obstacles. Based on the real measurement results obtained from the experiment, we demonstrated that with a presence of radio irregularity and signal attenuation, the transmission range measured of the mote is not uniform in all directions which mostly depends on the existence of obstacles. Then, we mathematically proposed a practical radio model which accurately examines the impact of signal attenuation and radio irregularity, called radio irregularity obstacles-aware model (RIOAM).

The organization of this paper is as follows. Section II provides a brief survey of related works. Section III describes details of our proposed radio irregularity obstacle-aware model. In Section IV, then, the experimental results including a performance comparison against a radio irregularity model (RIM) are discussed. Finally, the conclusions and future work are discussed in Section V.

II. RELATED WORK

For decades, the phenomenon of radio irregularity has been investigated in the literature [5-6, 9-11]. In [5], T. He *et al.* presented an irregular radio model which they called degree of irregularity (DOI). They introduced two bounds, i.e., upper (U) and lower (L), where the radio propagation range is either guaranteed or not. If the distance (d) between a pair of nodes (neighboring nodes) is between these two boundaries ($2L<d<2U$), the communication will depend on the actual communication range in a specific direction. In this model, the calculation of communication range in each direction depends on a pre-assigned irregularity metric which is also called DOI metric.

Although DOI was the first proposed radio model, it is well-known and considered as a good start for signal irregularity representations in the research community. However, there remains some limitations. For example, DOI does not take the environment factor into account and it usually results in indeterminable and unforeseen changes of radio range values in all directions.

In [9], S. Biaz *et al.* presented a realistic radio range irregularity (RRI) model. The authors implemented experiments and measurements of signals in different environments based on a wireless local area networks standard (IEEE 802.11) at a high frequency (2.4 GHz); however, the key limitation of this findings is not to classify the signal strength attenuation with various obstacles in a specific environment.

In [10], G. Zhou *et al.* introduced a new radio model, called radio irregularity model (RIM) as an extension of DOI model through a combining of the previous work, T. He *et al.* [5], and considering the radio interference among the sensing devices. The authors performed the experiment with two MICA2 motes. Then, they developed the radio propagation model to analyze the impact of radio range irregularity with regard to MAC and routing protocols.

In addition to the unstraight forward and the complexity nature of the dependent path loss model and energy-fading pattern on the multipath route, RIM can be considered as the maximum range variation per unit degree change in the direction of radio propagation. However, RIM does not explicitly express the variation probability of the communication range of each sensor in relationship with the radio parameters.

Thus, in this paper, with the objective on signal strength attenuation classification when the signal passes through different obstacles in the actual environment, we propose a new radio model based on RIM but with its improvement by considering the impact of obstacles to radio communication ranges.

III. RADIO IRREGULARITY OBSTACLE-AWARE MODEL

In this section, we introduce our proposed radio irregularity obstacles-aware model, i.e., RIOAM, based on RIM. First, we consider and perform some experiments in the particular case of sensing applications in the environment with various obstacles. Then, based on the experimental results obtained, we present details of practical radio model which accurately examine the impact of signal attenuation and radio irregularity.

A. *Test Bed Setup Analysis of Radio Irregularity due to Obstacles*

There are two main factors which cause the irregularity of radio signals, i.e., propagation media and devices. In this paper, we focus on the investigation of obstacle factors in a group of media properties.

To analyze the impact of obstacles to the radio propagation and signal power, we performed some experiments to study the radio irregularity using MICAz motes (See Figure 1) in environment with regard to various obstacles, such as human body, tree, glass wall, wooden wall, concrete wall, and metal door. We used two MICAz motes in our setup. The MICAz is a 2.4GHz IEEE 802.15.4 compliant. The mote module was used for enabling low-power, wireless, and sensor networks.

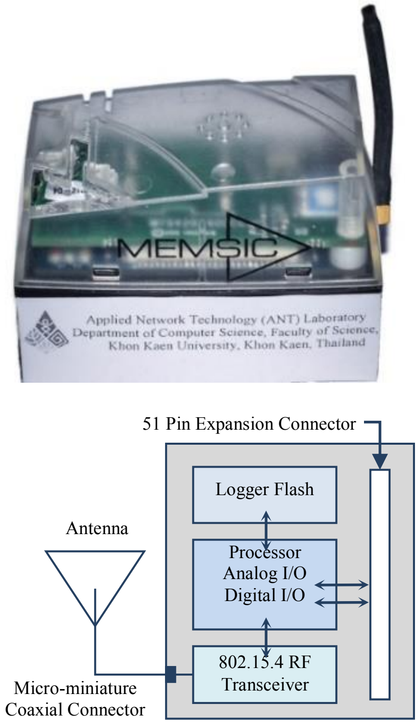
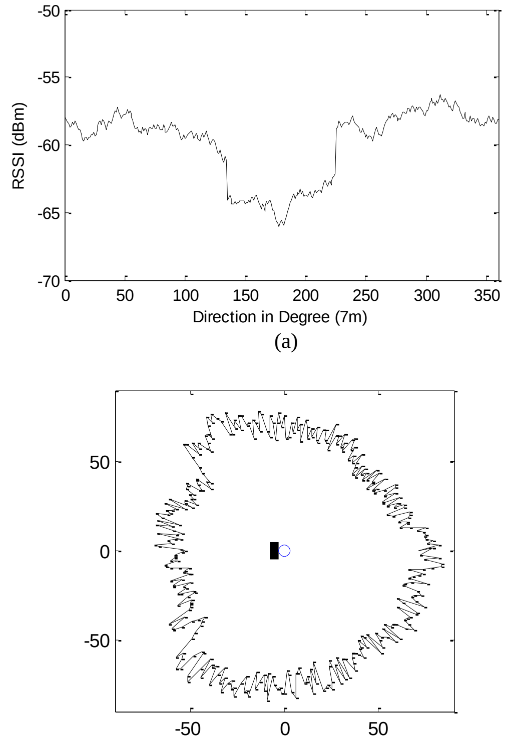


Figure 1: MICAzmote and its block diagram

To demonstrate the radio irregularity and signal attenuation, the communication range of a mote is not uniform in all directions and also depends on the existence and position of the obstacles. In our experiment, the receiver was placed at 7 meters away from the transmitter which was then placed 5 meters away from the obstacle. The received signal strength indicator (RSSI) was measured in many different geographical directions. Figure 2 shows the emulated results obtained from one of our experiments.

Figure 2a shows an example of RSSIs' variation. In general, RSSIs are in range from 0 to 359 degrees. In particular, the RSSI is significantly reduced when the signal goes through the obstacle. Figure 2b also shows the communication range behavior of a mote in different directions which in fact continuously varies with the direction. Note that these results are another confirmation of radio irregularity and signal power attenuation in a wireless medium.

We found that in the experiment with a glass wall (obstacle), the signal strength was attenuated around 2-3 dBm when the signal passed through the wall. While in the other experiment with a brick wall as the obstacle, the signal strength was attenuated around 5-7 dBm. We also performed some of the similar experiments with various obstacles. The results of these experiments showed that the signal strength attenuation was different in each case based on the type of the obstacles where are shown in Table 1.



(a)

(b)

Figure 2: Obstacle is a brick wall, (a) Signal strength values in different directions, (b) Communication range (m)

Table 1
Obstacle attenuation

Obstacles	Signal attenuation	Obstacle severity
Human body, tree, furniture, wooden door, clear glass, plasterboard wall	2-4 dBm	Low
Brick wall, metal window/door/wall	5-7 dBm	Medium
Concrete wall	8-10 dBm	High

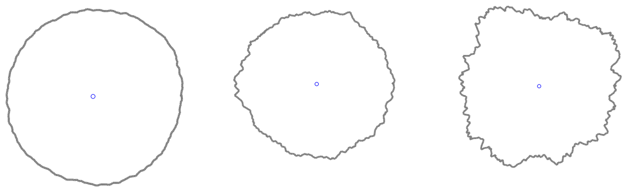
From this table, it can be concluded that the radio transmission of sensor devices at 2.4 GHz has the following main properties:

- The radio signal from a transmitter has various path losses in different directions.
- The radio communication range depends on the environment characteristic, especially with physical obstacles.

Depending on the presence of physical obstacles in each direction around the transmitter, the signal power experiences a specific attenuation in that direction.

B. *Modeling Radio Irregularity Obstacle-Aware*

Radio irregularity is caused by the presence of physical obstacles, irregularity of radiation pattern of transmitters, multi-path fading, and other environmental factors. As previously discussed, RIM is one of the well-known irregularity models. This model is a stochastic pattern for radio irregularity of transmitters and receivers, which defines the communication range as a variation of DOI changes. The DOI parameter is defined as the maximum path loss percentage variation per unit degree change in the direction of radio propagation. When DOI value is set to 0, there is no range variation (the communication range is a perfect sphere). However, with the increase of DOIs, the communication range becomes more irregular, as examples shown in Figure 3.



DOI=0.002 DOI=0.006 DOI=0.01

Figure 3: Degree of irregularity

RIM presents two main characteristics of radio irregularity, i.e., continuous variation and anisotropy. This model adjusts the value of path loss model based on DOIs, as presented in the following formula:

$$P_{\Gamma} = P_t - P_{DOI} + P_f \tag{1}$$

$$P_{DOI} = lxK_i \tag{2}$$

$$K_i = \begin{cases} 1, & i = 0 \\ K_{i-1} \pm RandxDOI, & 0 < i < 360 \end{cases} \tag{3}$$

$$\left|K_0 - K_{\partial 59}\right| \le DOI$$

where P_r and P_t are the received and transmitted signal powers of the receiver. P_{DOI} reflects the signals loss en-route to the receiver. P_r is the fading exponent; l is path loss parameter and K_i is a coefficient to represent the difference in path loss in various directions; namely, K_i is the i^{th} degree coefficient. Based on Equation (3), we can generate 360 values for the 360 different directions.

Based on the radio propagation model presented in the literature [5, 10], we propose a new radio irregularity model in the environment with obstacles, called RIOAM. The objective of this model is to calculate the impact of each obstacle and the attenuation of the signal strength when the signal passes through each specific obstacle. Approximately, RIOAM can calculate the communication range of each sensor node in the environment. Our model is presented by the following formulas:

$$P_r(d) = P_t - PL(d) \tag{4}$$

$$PL(d) = PL(d_o) + PL_{ob}(i) + 10xnx\lg\frac{d}{d_o}xK_i - X_{\sigma} \tag{5}$$

$$Pl_{ob}(i) = \begin{cases} 0 & , ob = 0 \\ \sum_1^{ob} PL_{ob}, & ob \ge 1 \end{cases} \tag{6}$$

where d is the communication range separation from transmitter and receiver; $PL(d)$ is the power loss corresponding to distance $d.d_o$ is a distance to the reference, such as $d_o = 1m$ and $PL(d_o) = 45dBm$. Note that $PL(d_o)$ does not have a specific formula; however, it usually is obtained by the calculation from the actual experiment. n is the path loss exponent standing for the rate at which the path loss increases with regard to the distance.

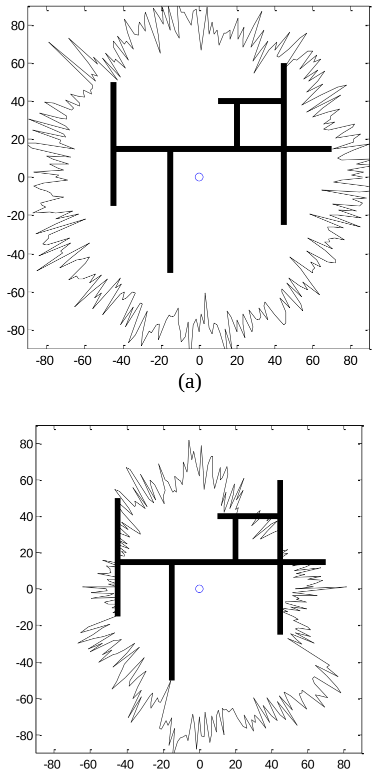
Note that typically, the path loss exponent is in between 1 and 7, depending on the specific environment. $X\sigma$ is used for the log-normal shadowing effect. $X\sigma$ is taken as a zero mean Gaussian random variable with standard deviation σ.The shadowing standard deviation σ heavily depends on the environment and could be in range from 2 to 14. ob is a number of obstacles encountered. $PL_{ob}(i)$ is the power loss due to the obstacles corresponding to the i^{th} direction. According to the Equation (4) and (5), we can calculate the communication range of the i^{th} direction as follows:

$$R_i = d_o x10\left(\frac{-P_{r\min} + P_t - PL(d_o) - PL_{ob}(i) + X\sigma}{10xnxK_i}\right) \tag{7}$$

where R_i is the distance of communication range of the i^{th} direction. $P_{r\min}$ is the minimum received power of the sensor which indicates that its received signal strength should be more than the minimum receiving sensitivity level for proper communication. For example, the typical RF (Radio frequency) receiving sensitivity level of MICAz mote is -94dBm. The following pseudo code provides the details of RIOAM. Note that here, d_{ob} is the distance from transmitter to obstacle.

Algorithm: RIOAM

```
for i=0 to 359 do
    $PL_{ob}=0$
    calculate $R_i$
    $ob=\{\emptyset\}$
    for j=1 to |ob| do
        if($d_{ob(j)}<R_i$)then
            $ob=ob+d_{ob(j)}$
        end if
    end for
    sort ob from min($d_{ob}$) to max($d_{ob}$)
    while |ob|≠0 do
        if($d_{ob(1)}<R_i$)then
            $PL_{ob}=PL_{ob}+PL_{ob(1)}$
            calculate $R_i$
            if($R_i<d_{ob(1)}$)then
                $R_i=d_{ob(1)}$
            end if
        end if
        $ob=ob-ob(1)$
    end while
end for
```



(a)

(b)

Figure 4: Comparison of RIOAM and RIM model on communication range, (a) RIM model, (b) Our proposed model (RIOAM)

Figure 4 shows the difference on the signal variation of the communication range in each direction between RIM and RIOAM. In opposite to RIM, with RIOAM, the signal attenuation is dynamic; the signal power attenuation depends on the existence of obstacles and the number of obstacles in each direction.

IV. EXPERIMENTAL ANALYSIS

In this section, we performed the experiment using MICAz [12] in our building at the Department of Computer Science, Faculty of Science, Khon Kaen University, Thailand. Here, we configured the motes and base station into 6 rooms at 21×14.7 m^2 including the pathway. There are two types of rooms in the area of 3.5×4.7 m^2 and 3.5×8 m^2 as shown in Figure 5. Note that some rooms have their own characteristics. For example, the three rooms were merged into one (on the bottom left and right but with some space for fire escape). Based on the results obtained, we discuss and compare our proposed model (RIOAM) with RIM including the real measurements.

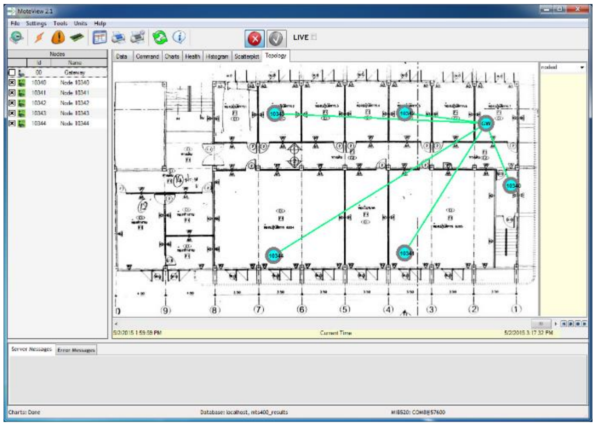


Figure 5: Motes deployment

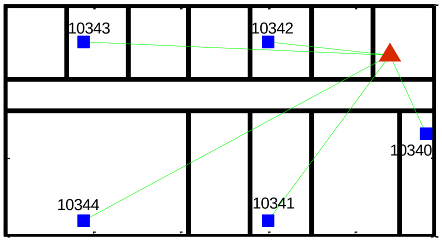


Figure 6: Modeling of the experiment

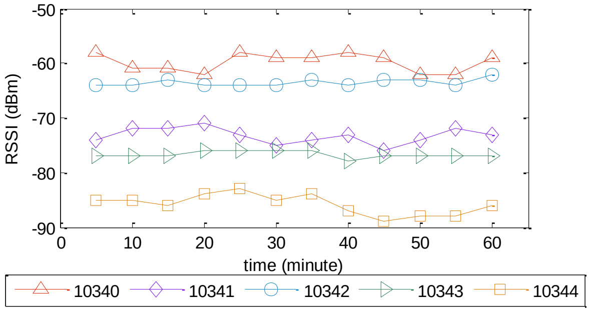


Figure 7: The RSSI metric of MICAz motes are measured in the experiment

In our experiment, we used 5 MICAz motes (MPR2400CA) with additional one as the base station (BS) (MIB520CB). The identification (ID) of each mote in turn are as follows: 10340, 10341, 10342, 10343, and 10344. The distance between BS and motes are 5.5, 13, 7, 17.5, and 21 (m), respectively. Here, MICAz motes play the key role as the transmitter and BS as the receiver. The devices were deployed in a floor of building consisting of many rooms (See Figs.5 and 6). We also used MoteView 2.1 software [13] to collect the RSSI data. The RSSIs were periodically collected every 5 minutes in a period of 1 hour. The real measurement results are shown in Figure 7.

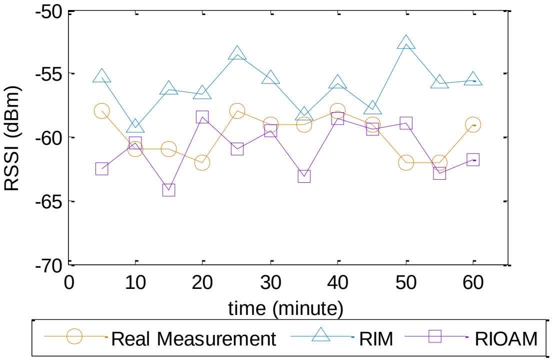
In this figure, there is a special point which we can see in the real measurement results in that the RSSIs of motes 10342 and 10343 are rather stable than the others (10340, 10341 and 10344). This is understandable because the position of latter three motes are located far from the BS. In particular, they are separated by a corridor, where there are multiple moving objects (like human). That is why the RSSIs obtained from three nodes are not stable and volatility over time.

In order to evaluate the effectiveness of RIM vs. our proposed model, a MATLAB simulator was used. Table 2 contains the standard parameters used in the simulation. Note that the standard parameter is referred from real measurement results of MICAz.

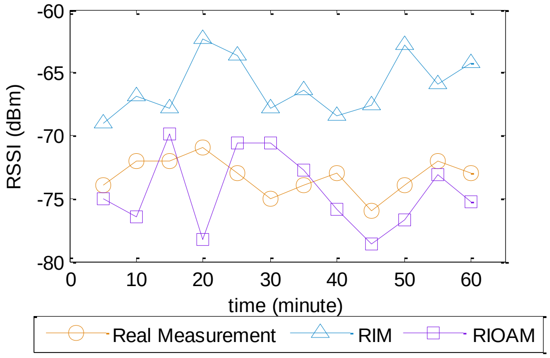
Figure 8 also shows the comparison of RSSI metrics of RIM, RIOAM, and the real measurement results. Considering RIM and RIOAM, the simulation results for each node are averaged for 10 times of each simulation run. As we can see in five sub-figures (8a to 8e), basically, five nodes with various locations all show relatively similar results. The RSSIs of RIOAM is very similar to the results of the real measurements. While RIM has higher RSSIs. This show that RIOAM is a more accurate irregular radio model for WSNs in the environment with a presence of obstacles.

Table 2
Simulation parameters

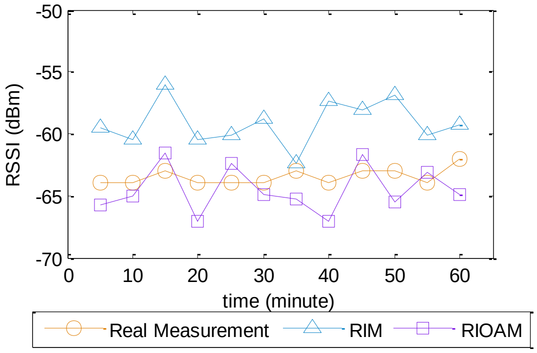
Parameters	Symbol	Value
Distance to the reference	d_0	3 m
Power loss corresponding to distance	$PL(d_0)$	-45 dBm
Transmitted signal power	P_t	0 dBm
Degree of irregularity	DOI	0.01
Path loss exponent	n	3
Log-normal shadowing effect	σ	3
Minimum received power	$P_{r\min}$	-94 dBm
Obstacle attenuation	PL_{ob}	[2,3] dBm



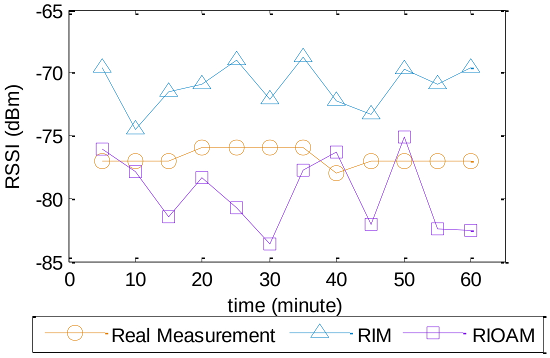
(a) Mote 10340



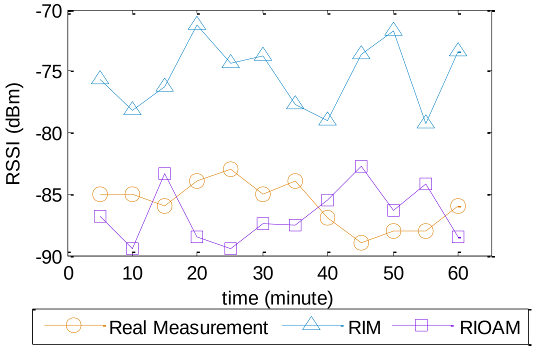
(b) Mote 10341



(c) Mote 10342



(d) Mote 10343



(e) Mote 10344

Figure 8: RSSIs of all motes

V. CONCLUSIONS

In this paper, we have proposed a new radio irregularity model used to simulate realistic applications in WSNs in order to enhance connectivity evaluation, especially for the applications in the environment with obstacles. Based on the real measurement results obtained from the actual experimental, we presented a radio model in order to exactly evaluate the impact of different obstacles in the environment to the signal power. Through the simulation and real measurement results, we demonstrated the correctness of using our proposed model. Our model can be good supports for applications needed to deploy the sensor nodes in the environment with a presence of many obstacles, specifically applications required high coverage and connectivity. For future work, it can be carried out under various environments. We also have plan on applying our radio model on the optimization of routing protocol with awareness of obstacles.

REFERENCES

[1] Cordeiro, C.M., Agrawal, D.P., “Ad hoc & sensor networks: theory and applications,” *World Scientific Publishing*, 2006.

[2] Akyildiz, I.F., Vuran, M.C., “Wireless sensor networks,” *John Wiley & Sons*, 2010.

[3] Hekmat, R., Mieghem, P.V., “Connectivity in wireless ad-hoc networks with a log-normal radio model,” *Mobile Networks and Applications*, vol. 11, no. 3, pp. 351-360, 2006.

[4] Shankar, P.M., “Introduction to wireless systems,” *John Wiley & Sons*, 2001.

[5] He, T., Huang, C., Blum, B.M., Stankovic, J. A., Abdelzaher, T., “Range-free localization schemes for large scale sensor networks,”*In: Proceedings of the 9th International Conference on Mobile Computing and Networking*, pp. 81-95, New York, USA, 2003.

[6] Arfaoui, I., Bellazreg, R., Boudriga, N., “A novel realistic irregular radio model to enhance coverage evaluation in wireless sensor networks.,” *In: Proceedings of International Confe-rence on Software, Telecommunications and Computer Networks (SoftCOM)*, pp. 160-164, 2014.

[7] Rappaport, T.S., “Wireless communications: principles and practice (2nd Edition),” *Prentice Hall communications engineering and emerging technologies series*, 2002.

[8] Sklar, B., “Digital communications: fundamentals and applications (2nd Edition),” *Commu-nications Engineering Services and University of California*, Los Angeles., 2006.

[9] Biaz, S.,Ji, Y., Qi, B., Wu, S., “Realistic radio range irregularity model and its impact on localization for wireless sensor networks,” *In: Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 669-673, 2005.

[10] Zhou, G., He, T., Krishnamurthy, S., Stankovic, J.A., “Models and solutions for radio irre-gularity in wireless sensor networks,” *ACM Transactions on Sensor Networks*, vol. 2, no. 2, pp. 221-262, 2006.

[11] He, D., Mujica, G., Liang, G., Portilla, J., Riesgo, T., “Radio propagation modeling and real test of ZigBee based indoor wireless sensor networks,” *Journal of Systems Architecture*, vol. 60, no. 9, pp. 711-725, 2014.

[12] MICAz.: http://www.memsic.com/userfiles/files/Datasheets/WSN/micaz_datasheet-t.pdf

[13] Mote-View 1.2 User’ Manual. Crossbow., 2006.