Path Loss Exponent Estimation using Connectivity Information in Wireless Sensor Network

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***Abstract*—In wireless fading channels, the path-loss exponent (PLE) is one of the most fundamental parameters to characterize the channel propagation. It has an important impact on the received signal strength (RSS)-based localization in wireless sensor networks (WSN). On the other hand, the communication range of a sensor in a WSN depends on the transmission power and on the environment (outdoor or indoor). Hence, the propagation conditions have a great influence on the connectivity between sensors in WSN, especially in complex environments. Nevertheless, most approaches used to estimate the PLE require some information of the wireless network such as RSS at some nodes, or some external information such as Global Positioning System. However, this information might be sometimes unreliable or difficult to obtain. In this paper, we propose a method to estimate the PLE based on the connectivity between sensors deployed in a determined area.**

Keywords— connectivity; range of communication; path loss exponent; received signal strength; wireless sensor network

I. INTRODUCTION

In recent years, researches in wireless communication have been widely interested in the field of wireless sensor networks (WSN). One of the most important applications in WSN is localization. Localization techniques can be classified into two main categories, either as range-based or range-free methods. Range-based are distance/or angle estimation based techniques, the range estimation is usually based either on RSSI, time of arrival (TOA), time difference of arrival (TDoA), angle of arrival (AoA), or their combinations. Whereas, range-free methods do not require distance or angle estimations; they use radio-connectivity to communicate between nodes to infer locations [1].

Among these several techniques, the solution based on the received signal strength (RSS) presents an interesting approach, since it is simple and inexpensive. Nevertheless, the instability and the complexity of channel models especially in harsh environment (such as mine environment) reduce the accuracy of location estimation, and decrease the efficiency of the RSS-based technique, because RSS is significantly affected by noises, multipath, barriers, etc. Hence, this technique is considered a big challenge for industries as well as academic researches. Though, the path loss exponent is considered as the main factor in the propagation model regardless the variation of the latter. Inaccurate values of PLE increases the error when used to estimate distance using RSS. Consequently, a correct estimation of PLE enhances the distance estimation. Researchers have investigated many methods to estimate PLE. Some techniques consider the PLE known a priori in the WSN environment. Other techniques rely on channel measurements to estimate PLE [2] [3]. Other methods begin with an initial guess of the PLE to estimate node's location, which is then used to update the value of the PLE [4]. However, these techniques depend on the information from reference nodes pre-deployed in the networks (RSS measurements), or on other auxiliary systems. Hence, if these information or systems are unavailable or unreliable, PLE estimation and then location estimation will be greatly erroneous.

In this paper we propose a method to estimate the PLE, based on the connectivity between sensor nodes deployed in a determined area.

The remainder of this paper is organized as follows. After this introduction, section II describes the system model considered in this work. Section III presents our proposed method and some results obtained in PLE estimation. Finally, section IV concludes this work.

II. SYSTEM MODEL

A. Propagation Model

Most wireless devices can measure the RSS Theoretical analysis and measurements prove that the signal strength received by a sensor from another sensor is a decay function of the distance separating these nodes [1]. This relationship can be modeled by the log-normal shadowing model, which is widely used for link budget analysis in wireless communication. Parameters of this model presented in (1) can be configured according to environment conditions.

$$P_r(d)[dBm] = P_0(d_0)[dBm] - 10 n_p \log \frac{d}{d_0} + X_\sigma \,. \quad (1)$$

where $P_r(d)[dBm]$ is the received power at distance d from the transmitter, $P_0(d_0)[dBm]$ is the received power measured at reference distance d_0 from the transmitter, n_p is the PLE, and X_σ is a zero mean Gaussian random variable with standard deviation σ , which represents the random effect caused by shadowing.

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B. Network Model

Capabilities of multifunctional sensor node communicating on short distances allow the implementation of WSN, which become essential in many applications and fields. Sensor nodes are deployed in an unknown topology, and are divided into two types; anchor nodes which know a priori their positions, and unknown nodes. Nodes are considered neighbor nodes if they are in the range of communication of each other. Hence, because of the random topology of WSN, a node can ideally have its neighbors randomly deployed within its transmission range, *R*. In other words, a node *A* is considered node's *B* neighbor if *A* can hear *B* without an intermediate node, that is the communication is done within one hop. Thus, the power of received signal at *B* must be greater than a threshold power ($Pr_{AB}>P_{threshold}$).

C. Connectivity Model

In order to estimate the PLE, a conversion of the RSS values into connectivity should take place. Two nodes are connected if $Pr\ (d)>P_{threshold}$. This connectivity is described by connectivity matrix $M_{N\times N}$ such as

$$M=[m_{ij}]_{N\times N}$$

$$m_{ij}=\begin{cases} 1 \quad if\, P_r(d_{ij})\geq P_{threshold}\ (d_{ij}\leq R) \\ \qquad\qquad i=1:N,\ j=1:N,\ i\neq j \\ 0 \quad if\ P_r(d_{ij})<P_{threshold}\ (d_{ij}>R) \end{cases}. \quad (2)$$

III. Proposed Method and Some Simulation Results

During information exchange each node can know its neighbors and thus the connectivity matrix *M* can be built. In fact, to avoid having disconnected nodes, all nodes should have neighbors. However, if the propagation model is complex, nodes will not communicate easily and to assure one connected network, more nodes will be needed to be deployed, thus, the density of the connected network is related and affected by the propagation condition; so by the PLE value.

We begin our study using a simple 1-D topology of WSN, and by assuming a homogenous medium. *N* unknown nodes are randomly, uniformly deployed covering a total distance *d*. At each extremity one anchor node is placed (Fig. 1). The density of node's deployment λ is thus known. The information can be transmitted between the two anchors, thus, each node has neighbors. We adopt a constant number of nodes (*N=50*) deployed randomly over a distance ($d_{total}=200\ m$). We assume $d_0=1m$, and $\sigma=\{0;\ 3\}$. For different values of *R* (*10m<R<100m*) different *M* are obtained. For each value of *R*, 100 random topologies are generated and an average connectivity *k* is then calculated (*k=20 means that the average RSS of 20 nodes are above the threshold*).

To estimate the PLE, we are based on the fact that *k* depends on the environment, hence, the value of *n*, and for each value of *R*, characterizing a value of *n,* a matrix *M* is obtained. Thus, based on *k*, λ, and *N* in the network, we can build the relation in (3) between these different parameters to estimate $\hat{n}$.

$$\hat{n}=\frac{k\times\lambda}{N\times 2}. \quad (3)$$

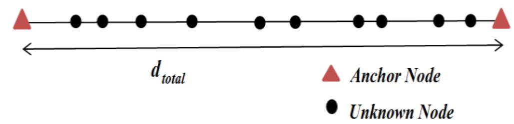

Fig. 1. One- Dimensional Linear Topology of WSN

Fig. 2 presents error on the PLE estimated in function of *k,* for two values of σ. The black curve presents the error on the estimation of PLE in case of absence of shadowing effects (σ=0). Whereas, the red curve presents the error of PLE estimation with σ= 3. Results show that PLE estimation error using the approach based on the connectivity of the network is very low ($0.1<e_n<0.6$). Also, it is clear from Fig. 2 that shadowing effects do not affect a lot this estimation (σ=3dB, $0.15<e_n<0.6$). Hence, contrary to some methods assuming a constant and a priori known value of PLE, and, unlike approaches using the value of the received signal strength which can be unreliable, our approach proves that using the connectivity a good estimation of PLE can be done, avoiding using unreliable or difficult information to estimate PLE.

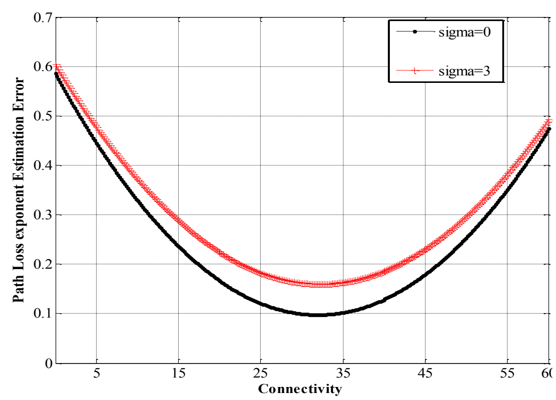

Fig. 2. Path Loss Exponent Estimation Error

IV. Conclusion

In this paper, we presented a method to estimate the PLE of a propagation environment based on the connectivity between nodes in a WSN. Results obtained show the efficiency of this method, regardless values of RSS. Further work will be done to extend this approach, such as estimating PLE in 2-D topology. Moreover, having better estimated value of PLE, RSS-based technique can be better interpreted, hence, errors on localization will decrease.

References

[1] W. Dargie and C. Poellabauer, Fundamentals of Wireless Sensor Networks Theory and Practice, John Wiley & Sons Ltd, United Kingdom 2010.

[2] C. Chin Pu, S. Y. Lim, and P. Cheng Ooi, "Measurement arrangement for the estimation of path loss exponent in wireless sensor network," in 7th ICCCT , pp.807-812, Dec. 2012.

[3] A. Golestani, N. Petreska, D. Wilfert, and C. Zimmer, "Improving the precision of RSSI-based low-energy localization using path loss exponent estimation," in 11th WPNC, pp.1-6, March 2014.

[4] M. Gholami, R. Vaghefi, and E. Strom, "RSS-based sensor localization in the presence of unknown channel parameters," IEEE Trans. Signal Process., vol. 61, no. 15, pp. 3752–3759, Aug. 2013.