International Journal of Electronics Communication and Computer Engineering
Volume 4, Issue 4, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Performance Evaluation of Link Quality Indicator of a Wireless Sensor Network in an Outdoor Environment

S.U. Nnebe, G.N. Onoh, C.O. Ohaneme, K.A. Akpado

***Abstract* - Wireless Sensor Network (WSN) has in recent times solved the problems associated with remote sensing and monitoring. However, link quality had been the major key player in the sensing and transmission of sensed signals to remote places especially in WSN. In this work, the effects of link quality indicators in an outdoor monitoring environment were investigated. The investigation carried out helps in evaluating the performance of these indicators to the monitoring capability of WSN in linear topology system. The outdoor environment of the Digital Library of Nnamdi Azikiwe was used as the experimental testbed environment to showcase the effect of Link Quality Indicators (LQI) on the Received Signal Strength (RSS) of the sensed signals in WSN. The results obtained from the measurement carried out and the simulation show that the qualities of the RSS of the transmitted signal from the WSN play vital roles in the monitoring and detection system. It therefore can be inferred that the accuracy of the detection and monitoring of a particular environment depends squarely on the LQI of the system (environment) under study.**

***Keywords* – Correlation Value, LQI, Packet Reception Rate, Sensor Nodes, Telos B, WSN.**

I. INTRODUCTION

In communication networks the quality of transmitted signals through wireless system form the bases of evaluating the nature and manner the transmitted data are received at the receiving end. The importance of monitoring and control of these transmitted data cannot be over emphasized because of the need to see what happens to the transmitted signals on transit and the desire to eliminate the captured constraints. To see to the proper monitoring of the wireless system, Wireless Sensor Network (WSN) can be deployed to the monitoring environments to sense, analyze and transmit/retransmit the data from remote distances wirelessly. More often the quality of these transmitted signals need to be evaluated so that error detection, correction and control can be effected simultaneously in order to obtain an error free result. Therefore, this work provides the frame work for the evaluation of the performance of the radio link quality indicator to ascertain the optimum delivery of the sensed data at the sensor nodes. The sensor nodes deployed are arranged in linear topology configuration. To achieve the aim of the real time measurement of the detected signal, IEEE 802.15.4 compliant sensor networks was used to evaluate and show the wireless links between the source sensor nodes and the sink nodes.

IEEE 802.15.4 radios provide applications with information about the incoming signal when used for communication [1]. The link quality indicator (LQI) is a metric introduced in IEEE 802.15.4 standard [2] and is provided by CC2420 which is the transceiver in the sensor node used in the experiment. If there is no interference from other 2.4GHz devices, then LQI will generally be good over distance.

In wireless sensor networks (WSNs), link quality estimation is more challenging than in traditional wireless networks, due to factors such as network density, network dynamics and the use of low cost, low power radio transceivers. It has been experimentally shown that low-power radios are more prone to noise, interference, and multipath distortion [3]. As a result, communication links in WSNs exhibit more unreliability as compared to those of traditional mesh and adhoc networks [4]- [5].

II. RELATED WORKS ON LINK QUALITY INDICATORS (LQIS)

There are several recent works that have introduced new link quality estimation metrics of WSNs [6]- [7]- [8] and others have assessed the convenience of traditional estimation metrics for WSNs [8]. Besides, the works of [9] shows the deployment of WSNs in the monitoring and evaluations of faults in smart grid power systems. The paper focuses on the performance of different types of Link-Quality Estimators (LQE) in different smart power grid environments to quantify the impact of the smart grid propagation environment characteristics on the overall network performance in smart grid spectrum environments in terms of packet delivery ratio, average number of packet retransmissions, average number of parent changes, average number of hops, and average communication delay. Their works considered several key LQE such as Packet Reception Rate (PRR), Required Number of Packet Transmissions (RNP), Window Mean with Exponential Weighted Moving Average (WMEWMA), Expected Transmission Count (ETX) and Four-Bit. Amongst these LQE methods deployed, the study shows that ETX and Four-bit show the best performance in harsh smart grid environments. Also, [10] proposed the analysis of link quality prediction algorithm for WSNs to determine the rate of deterioration in the communication channels of sensor network. Symbol Aggregation Approximation (SAX) method was deployed where LQIs were mapped into different symbols and summarized the preceding symbols of link quality deterioration in the collection of patterns. The result from the experimental data obtained showed that the proposed method can predict a high degree of deteriorations in the network. [11] conducted a comprehensive survey on the link quality estimation in WSNs and its impact on the network performance and their effects the design of higher layer protocols. The paper provided a comprehensive study and the taxonomy of various existing LQE to evaluate their performances in terms of service delivery in WSNs. The results showed that the survey conducted appeared to be optimum in the estimation of link qualities in WSNs.

Wireless network behaviour is largely influenced by the performance of the wireless links between the nodes of the network. Performance of a wireless link between a transmitter and receiver is determined by the RF channel between the terminals (environment model) and the bit-error-performance of their wireless transceivers (radio model). RF channel models describe the probabilistic relation between link distance and pathloss. In any given network, links of same length experience different channel realizations due to spatial variations in obstructions and reflectors in the scene.

The technique deployed in the work shows that the real time measurement and simulation model obtained provided the best framework for the evaluation of link qualities in WSNs.

III. RESEARCH METHODOLOGY AND SYSTEM ANALYSIS

Real-time experiments were conducted to estimate the Link Quality of Wireless Sensor Nodes in an outdoor environment. The aim of the experiments was to determine the quality of the link of the testbed environment for developing a linear long distance structure that would be used for pipeline monitoring. The development kit used is Crossbow TelosB sensor node from Texas Instrument which uses CC2420 transceiver- an IEEE 802.15.4 radio with a built in 2.4GHz antenna. An ideal environment was created by avoiding confounding factors that would spuriously affect the quality of the link.

The experimental set up consisted of four crossbow TelosB sensor nodes programmed with NesC programming language. The program for the collection of data and the graphical user interface display of the sensor node was written in Java language. The program displays the data received and also shows graphical relationship of the sensor node for voltage, temperature, light intensity, humidity. The graphical display has options for save data, clear data, start monitoring and stop monitoring. The nodes are programmed to send data every 5 seconds. The data collected over a long period of time was averaged and used for analysis.

One of the sensor nodes was attached to the laptop through a USB cable and was used as the sink. The remaining three sensor nodes were placed at 0^0, 90^0, 180^0 from the sink at the same distances while taking the measurements. This was done to get approximately all round readings of the signal. The measurements were taken from 5m to 60m distance at the interval of 5m. At each distance reading were taken for 2 minutes giving a total of 20 readings for every distance. The mean of LQI value obtained at a given distance was calculated.

A. Link Quality Indicator Model

IEEE 802.15.4 radios provide Link quality information about the incoming signal when used for communication called Link Quality Indicator (LQI). The effect of distance on received signal strength (RSS) can be measured by the Packet Reception Rate (PRR), Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI) provided by the radio. LQI as a metric introduced in IEEE 802.15.4 measures the error in the incoming modulation of successfully received packets (packets that passed the CRC criteria). The LQI metric characterizes the strength and quality of a received packet. LQI measures each successfully received packet and the resulting integer ranges from 0x00 to 0xff (0 – 255), indicating the lowest and the highest quality signals detectable by the receiver (between – 100dBm and 0dBm). The correlation value of LQI range from 50 to 110 where 50 indicates the minimum value and 110 represents the maximum. LQI is calculated using software in the transceiver as [1].

$$LQI = (CORR - a).b \qquad (1)$$

where *CORR* is the Correlation value, *a* and *b* are found empirically based on Packet Error Rate (PER) measurements as a function of the correlation value. The correlation value (CORR) is the raw LQI value which can be obtained from the last byte of the message. A combination of RSSI and correlation values may also be used to generate the LQI value which is uniformly distributed between the upper and lower units. LQI can be viewed as chip error rate and is calculated over 8 bits following the Start Frame Delimeter (SFD). This is as shown in a model of equation 2.

$$LQI = -0.33 * d + 110 \qquad (2)$$

where *d* is the distance.

IV. RESULT ANALYSIS

Data obtained from the real time measurements were evaluated and graphs were plotted to show how the quality of the link varies with distance. Microsoft Excel Work sheet was used to plot a multiple bar chart showing the relationship between the mean LQI of the three sensor nodes with their average.

Table 1: The Measured LQI values

Dist. (m)	LQI of node ID 301	LQI of node ID 302	LQI of node ID 303	Aver. LQI of 3 nodes
1	107.7	107.3	107.6	107.5
5	107.2	107.5	106.9	107.2
10	106.8	107.1	106.9	106.9
15	100.6	106.3	107.5	104.8
20	106.9	106.7	104.6	106.1
25	106.8	107.5	106.8	107.0
30	106.5	95.6	94.7	98.9
35	99.1	95.6	104.2	99.6
40	107.2	93.6	105.1	102.0
45	105.8	97.7	104.8	102.8
50	105.5	83.3	80.7	89.8
55	106.7	100.2	97.3	101.4
60	78.8	78.7	77.1	78.2

Table 1 shows the LQI values against distances measured in the testbed. The Average LQI of the three sensor nodes against distance is also shown in Table 1. The bar chart of Fig. 1 shows the mean LQI of the three sensor nodes and their averages while the plots of the average LQI of the three sensor nodes are also shown in Fig. 2. The LQI of the average of the three sensor nodes is shown in Fig. 3. The LQI was plotted against distance to show its variation with increase in distance. It can therefore be deduced that the measured LQI values fluctuate with distance due to some prevailing environmental conditions where the WSNs are deployed.

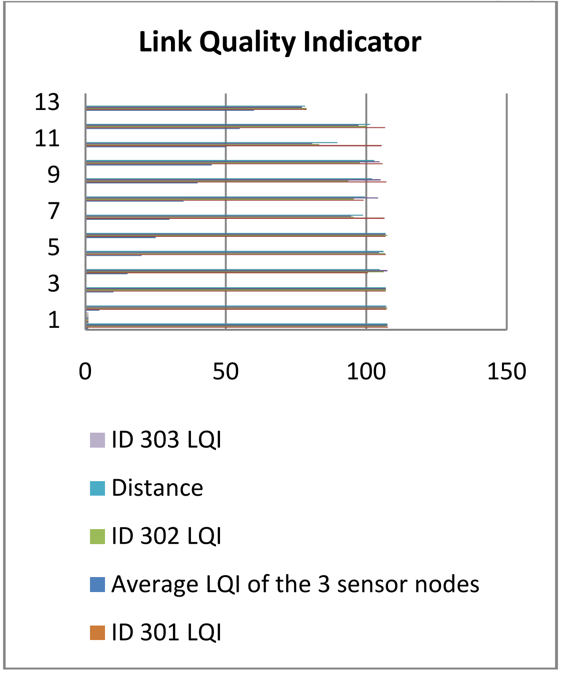

Fig.1. Bar chart showing the mean LQI of the three sensor nodes and their average.

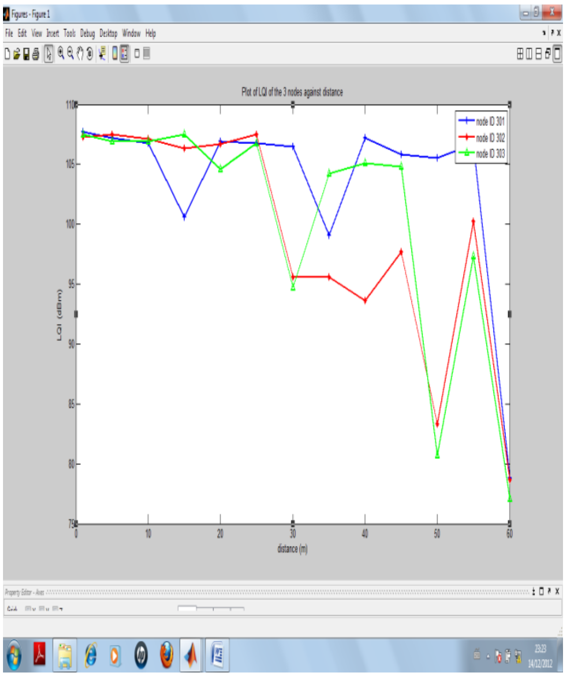

Fig.2. Plot of Mean LQI of the three nodes against distance

Ench sensor node that is deployed to sense and transmit the sensed data is associated with some environmental factors that may be different fom those of other neighboring nodes. This makes the quality of the measured data at each node to be different from each order, as can be seen in both Table 1 and Figs. 1 and 2. The average plot in Fig. 3 shows that the variations is in tandem with that obtained in Fig.2.

A model equation of LQI of the testbed environment was developed by finding the least mean square error line of the measured points using the method of linear regression analysis. The developed model is used to obtain the graphical result shown in Fig. 4.

The LQI in the testbed environment follows the trend given by equation 2 such as

$$LQI = -0.33 * d + 110 \qquad (2)$$

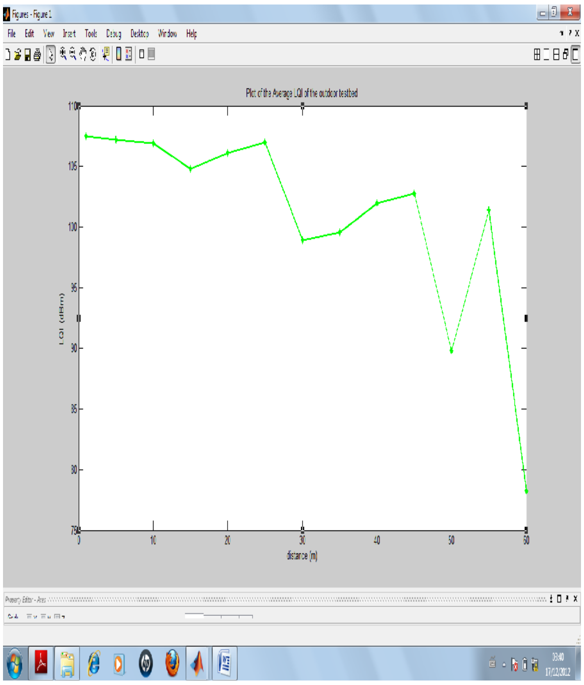

Fig.3. Plot of Average LQI of the 3 nodes against distance

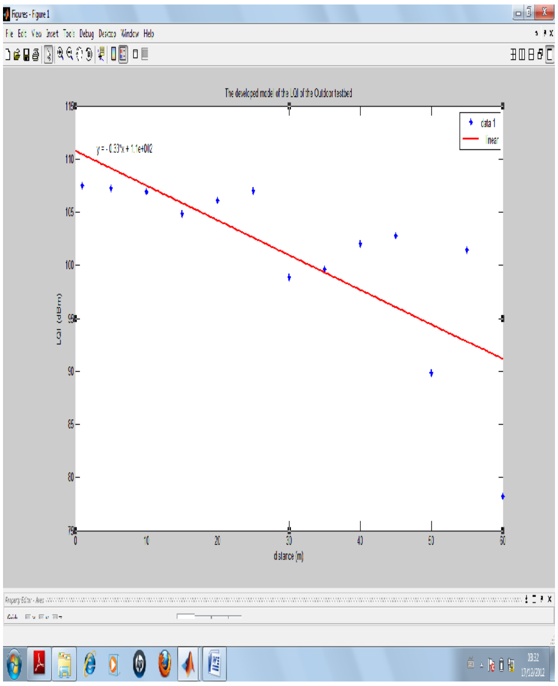

Fig.4. Plot of the model of the LQI of the testbed environment

V. CONCLUSION

Since it is the desire that all the transmitted data be received without any error, therefore this work succeeded in evaluating the performance of link quality indicator in wireless sensor networks. The effectiveness of any monitoring system is its ability to sense, process or evaluate and transmit the sensed data correctly from remote places. This paper therefore ensures that proper monitoring and evaluation of signals obtained from detected signals from sensor nodes are used to ascertain efficient monitoring of pipeline system using WSNs for instance.

The LQI at any known distance can be calculated using the developed model equation of the testbed environment. From the measurement taken, it was observed that the link quality of the environment ranges from 107.5 to 78.2 which correspond to distances 5m and 60m respectively. This indicates a good link. Since the quality of the link is good, the RSSI of the environment was also good.

REFERENCE

[1] Chipcon, *"CC2420 low power radio transceiver datasheet"*, http://www.chipcon.com. 2005.

[2] IEEE std. 802.15.4, *"Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Low Rate Wireless Personal Area Networks (LR-WPANs)"*, IEEE Transactions for Mobile Communications 2003. http://standards.ieee.org/getieee802/download/802.15.4-2003.pdf

[3] Tang, L., Wang, K.C., Huang, Y. and Gu, F., *"Channel Characterisation and Link Quality Assessment of IEEE 802.15.4-Complaint Radio for Factory Environments"*, IEEE Trans. Industrial Informatics, Vol.3, No. 2 2007, Pp. 99-100.

[4] Cerpa, A., Wong, J.L., Potkonjak, M. and Estrin, D., *"Temporal Properties of Low Power Wireless Links: Modelling and Implications on Multi-hop Routing"*, in mobiHoc '05: Proceedings of the 6th ACM International Symposium on Mobile Adhoc Networking and Computing. New York, NY, USA 2005, Pp. 414-425.

[5] Zhou, G., He, T., Krisnamurthy, S. and Stankovic, J.A., *"Impact of Radio Irregularity on Wireless Sensor Networks,"* in MobiSys '04: Proceedings of the second International Conference on Mobile Systems, Applications, and Services, New York, NY, USA, 2004 Pp.125-138.

[6] Fonsecs, R., Gnawali, O., Jamieson, K. and Levis, P., *"Four-Bit Wireless Link Estimation"*, In proceedings of the sixth workshop on Hot Topics in Networks (HotNets VI) 2007.

[7] Senel, M., Chintalapudi, K., Lal, D., Kesharvazian, A. and Coyle, E.J., *"A Kalman Filter Based Link Quality Estimation Scheme for Wireless Sensor Network"*, IEEE Global Telecommunications conference 2007.

[8] Wang, Y., Martonosi, M. and Peh, L-S., *"Predicting Link Quality using Supervised Learning in Wireless Sensor Networks,"* ACM SIGMOBILE Mobile Computing and Communications Review, Vol.11, No.3 2007, Pp. 71-83.

[9] Gungor V.C. and Korkmaz, *"Wireless Link-Quality Estimation in Smart Grid Environments"*, International Journal of Distributed Sensor Networks Volume 2012, pp 1-10.

[10] Zhao Jindong, *"Study and Prediction of Wireless Link Quality for Adaptive Channel Hopping"*, Journal of Networks, Vol. 7, No. 11, November 2012, pp 1884-1891.

[11] Nouha Baccour, Anis Koubaa, Luca Mottola, Marco Antonio Zuniga, Habib Youssef, Carlo Alberto Boano and Mario Alves, *"Radio Link Quality Estimation in Wireless Sensor Networks: A Survey"*, ACM Transactions on Sensor Networks, Vol. No. January 2012.

AUTHORS' PROFILE

Scholastica Ukamaka Nnebe

holds B.Eng. and M.Eng. degrees in Electrical/Electronic and Computer Engineering and Communication Engineering from Nnamdi Azikiwe University Awka, Nigeria. She also holds Ph.D. degree in Communication Engineering in the department of Electronic and Computer Engineering of Nnamdi Azikiwe University Awka. Currently, she is a lecturer in the department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria. Her research interest is on Wireless Sensor Networks and System Engineering.
E-mail: su.nnebe@unizik.edu.ng, scholar.nnebe@gmail.com

Greg Nwachukwu Onoh

is a Professor of Communication Engineering in the department of Electrical/Electronic Engineering, Enugu State University of Science and Technology (ESUT) Enugu, Nigeria. He holds Ph.D in Communication Engineering. Currently, he is a lecturer in the department of Electrical/Electronic Engineering, Enugu State University of Science and Technology (ESUT) Enugu, Nigeria.
E-mail: onohnwachukwu@yahoo.com

Cletus Ogbonna Ohaneme

holds B.Eng. in Electrical/Electronic Engineering in 1994, M.Eng. and Ph.D. in Communications Engineering in 1998 and 2012 respectively; all from the department of Electrical/Electronic Engineering, Enugu State University of Science and Technology (ESUT) Enugu, Nigeria. He is currently a senior lecturer in the department of Electronic and Computer Engineering Nnamdi Azikiwe University Awka, Nigeria. His research interest is on Wireless Communication Networks and Spectrum Management.
E-mail: co.ohaneme@unizik.edu.ng and engrohaneme@yahoo.com

Kenneth Aghaegbunam Akpado

holds B.Eng. in Electrical/Electronic Engineering from Federal University of Technology Owerri, Imo State, Nigeria. He also holds M.Eng. and Ph.D degrees in Electronic and Communication, and Computer and Control Engineering respectively from Nnamdi Azikiwe University Awka, Anambra State, Nigeria. His research interest is on System Automation and Ccontrol.
E-mail: ka.akpado@unizik.edu.ng