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Experimental Characterization of Link Quality Indicator in an Indoor Environment using TelosB Sensor Nodes

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Abstract: Link Quality Indicator (LQI) is one of the important Link Quality Estimators (LQEs) in Wireless Sensor Networks (WSNs). However previous radios used in Wireless Sensor Network platform do not have LQI metrics in them. In this paper performance evaluation of LQI metric in an indoor environment was done. A test bed developed at the Faculty of Engineering building Nnamdi Azikiwe University was used. The test bed comprised of four sensor nodes in which one functions as the sink and the three others were placed at different angles with respect to the sink. Several measurements taken at different times were averaged, processed and analysed. LQI model of the test bed environment was developed using Linear Regression Analysis. The goodness of fit (R^2) of the developed model was found to be 0.80.This shows that the model is good and can comfortably be applied to any environment with similar radio characteristics.

Index terms: *TelosB node, Link Quality Indicator, Link Quality Estimator, WSN, test bed.*

I. INTRODUCTION

Several research papers focused on the statistical characterization of low-power links through estimation theory. This is commonly known as Link Quality Estimation and is used to study the behaviour of low-power links. Link quality estimation in Wireless Sensor Networks is a fundamental building block for several mechanisms and network protocols. For instance, routing protocols rely on link quality estimation to overcome unreliability of low-power links and maintain the correct network operation [1-4]. Delivering data over high quality links improves the network throughput by limiting packet loss. It also maximizes the link's lifetime by minimizing the number of retransmissions as well as avoiding route reselection triggered by links failure. Link quality estimation also plays a crucial role for topology control mechanisms in order to maintain the stability of the topology [5,6]. High quality links are long-lived; therefore, efficient topology control mechanisms rely on the aggregation of high quality links to maintain robust network connectivity for long periods, thus avoiding unwanted transient topology break down.

The radio hardware used in Wireless Sensor Network is one of the main causes of low power links unreliability. Since link quality depends on the radio hardware platform, it is necessary to discuss the characteristics of the radio in the sensor nodes used. The Sensor Nodes used in the experiment is Crossbow TelosB sensor node from Texas Instrument. It consists of four main sections namely; a processor (memory, A/D converter for connecting to a sensor), two 2AA batteries, a radio transceiver (CC2420) for forming an ad hoc network and the sensor unit which comprises of three sensors; humidity, temperature and light intensity sensors. The CC2420 transceiver is an IEEE 802.15.4 radio with an inbuilt 2.4GHz antenna. CC2420 radio chips are commonly found in several current WSN platforms due to its compliance with IEEE 802.15.4 standard. It has tendency for high data rate owing to the usage of WIFI chips. IEEE 802.15.4 radios provide applications with information about the incoming signal when used for communication [7]. The link quality indicator (LQI) is a metric introduced in IEEE 802.15.4 standard [8] 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 long distance.

In this work an experimental testbed comprising of four sensor node was setup to evaluate the performance of the link in the environment using link quality indicator metrics. Measurements were taken and data obtained were analysed and evaluated. The paper is sectioned as follows;

II. RELATED WORKS

Several works have been done by many researchers on link quality estimation. The authors in [9] analyzed and evaluated concurrent packet transmissions for mica2 motes. They showed that the signal to interference and noise ratio (SINR) threshold was different for different nodes. They also showed that the SINR depends on the RSSI. They suggested that these were due to hardware mis-calibration.

The authors in [10] studied the properties of RSSI so as to design an RSSI-based routing protocol as a link metric for static wireless sensor network. In this phase they studied the characteristics of RSSI and its implications on the packet error rate. Their key observations show that RSSI can be a potential wireless link metric which can be used to design a more stable routing protocol.

In [11] packet delivery behaviors in 802.11 networks were observed by the authors. They observed that the variations in received signals were most likely due to multipath effects as there was little correlation between PRR and SINR. However, their experimental methodology differs from those of the sensor network studies. For example, they consider average SINR ratios over second long periods rather than on a per-packet basis.

It was shown that there was no correlation between Packet Reception Rate and distance above 50% of a node's communication range by the authors in [12]. They also found many link asymmetries about 30%. They showed that these asymmetries were due to hardware miscalibration and not due to the environment.

In [13], the authors modeled and analyzed low power wireless links using communication theory. They identified the causes of transitional region and quantified their influence on the network. They also derived expressions for packet reception rate as a function of distance and for the width of transitional region. Their key finding is that for radios using narrow band modulation, the transitional region is not an artifact of the radio non ideality, as it will exist even with perfect threshold receivers because of multipath fading. However, they hypothesized that radios with mechanisms to combat multipath effects, such as spread spectrum and diversity techniques, can reduce the transitional region.

In all the previous work presented above for sensor networking, the authors evaluated the quality of the link using older radios. In this paper, the newer set of nodes called TelosB nodes (based on CC2420) was evaluated.

III. EXPERIMENTAL METHODS

In the experiments, TelosB sensor nodes which has CC2420 as the radio chip was used. CC2420 transceiver operates in 2.4GHz ISM band with an effective data rate of 256kbps. In 2.4GHz band, it has 16 channels numbered 11 through 26 with each channel occupying a 3 MHz bandwidth with a centre frequency separation of 5MHz for adjacent channels. CC2420 uses Offset Quadrature Phase Shift Keying (OQPSK) modulation technique which encodes 32 chips for a symbol of 4 bits. CC2420 provides LQI measurement which can be viewed as chip rate and is calculated over 8 bits following the start frame delimiter (SFD). LQI values are usually between 110and 50 which corresponds to maximum and minimum frames respectively.

Real-time experiments were conducted to estimate the Link Quality of the Wireless sensor nodes in an Indoor environment. The aim of the experiments was to determine the quality of the link of the test bed environment for developing a linear long distance structure that would be used for infrastructure monitoring such as pipeline, bridges, roads and so on. An ideal environment was created by avoiding obstacles like walls and furniture that would spuriously affect the quality of the link. To do this an empty corridor was used. The test bed environment is the corridor of the first floor of Goddian Ezekwem building wing B. 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 voltage, temperature, light intensity and 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 $0^{O,}$ 90^{O}, 180^{O} 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, readings were taken for 2 minutes. The mean of LQI value obtained at a given distance was calculated. LQI was calculated using software in the transceiver as in equation (1) adopted from [7].

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

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.

IV. RESULT ANALYSIS

Data obtained from the real-time measurements were evaluated and graphs 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. Also variance and standard deviation of the measured values were calculated to be 0.0224 and 0.1496 respectively.

Table 1: The Measured LQI values

Distance (m)	LQI of mote ID 301	LQI of mote ID 302	LQI of mote ID 303	LQI of the 3 motes
1	107.7	107.1	107.1	107.3
2	107.	107.2	106.5	107.1
3	106.2	107.3	107.8	107.1
4	107.4	107.3	107.2	107.3
5	107.1	106.6	106.9	106.9
6	107.1	107.1	107.4	107.2
7	107.3	107.2	107.5	107.3

Table 1 shows the LQI values against distances measured in the test bed. The Average LQI of the three sensor nodes against distance is also shown in Table 1.

The bar chart of Figure 1 shows the mean LQI of the three sensor nodes and their averages. The plots of the mean LQI of the three sensor nodes and the average of the mean

LQI of the three sensor nodes are shown in Figures 2 and 3 respectively using matlab software tool. The LQI was plotted against distance to show its variation with increase in distance. It can therefore be deduced from the plots that the measured LQI values fluctuate with distance due to some prevailing environmental conditions where the WSNs are deployed.

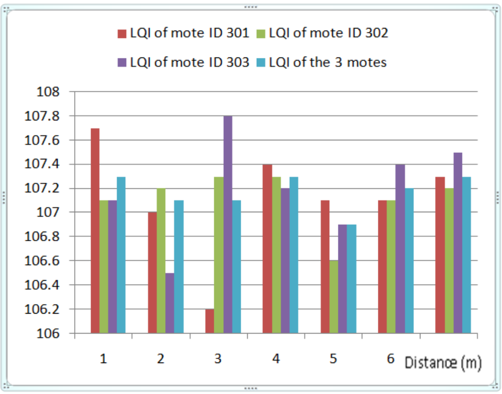

Fig.1. Bar chart showing the mean LQI of the three sensor nodes and their average.

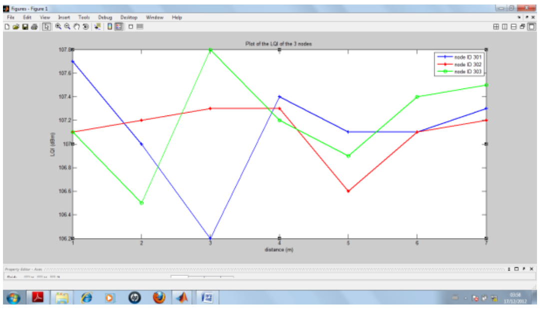

Fig.2. Plot of Mean LQI of the three nodes against Distance

The quality of the measured data at each node may be different from each other. This is due to the differing environmental effect on each node. The average plot in Figure 3 shows that the variation is in tandem with that obtained in Figure 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 graph of the developed model is shown in figure 4. Excel work Sheet was used to run Statistical Data Analysis and the screen shot is shown in figure 5. The LQI in the test bed environment follows the trend given by equation 2 such as

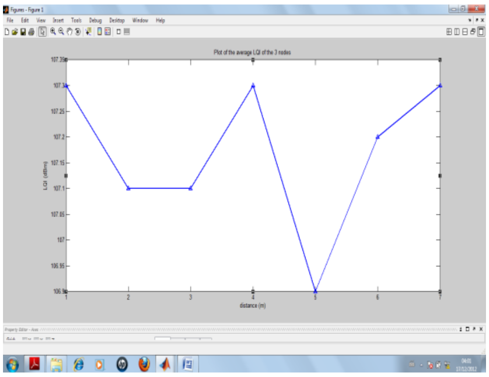

Figure3: Plot of the average LQI of the 3 nodes against Distance

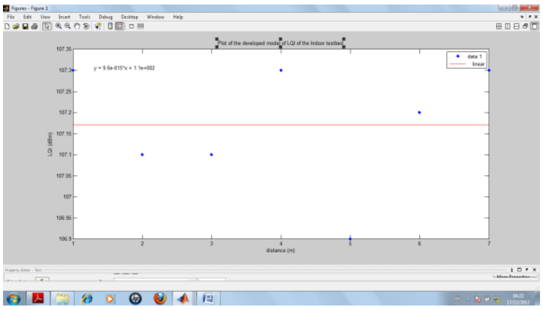

Figure 4: Plot of the developed LQI model of the indoor test bed

$$LQI = 9.6\exp - 15 * d + 110 \qquad (2)$$

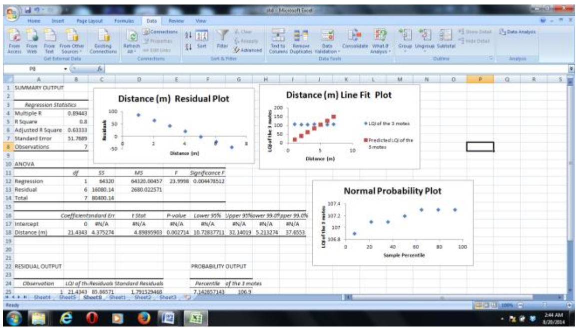

Fig 5: Screen shot of statistical data analysis of the LQI

The goodness of fit (R^2) of the Link Quality Indicator (LQI) model developed for the indoor testbed was tested and found to be 0.80.

V. CONCLUSION

LQI of TelosB sensor node from Texas Instrument was evaluated for indoor environment. TelosB sensor node contains CC2420 transceiver which is a newer radio for WSN platform. Measurements taken were evaluated and LQI model of the test bed environment was developed using Linear Regression Analysis. The developed model was tested and the goodness of fit (R^2) of the model was found to be 0.80 which shows that the model can be applied to an area with similar radio characteristics. Experiments performed showed that the LQI metric in CC2420 transceiver is a good metric for LQE.

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