# Experimental Investigation of Radio Performance in Wireless Sensor Networks

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***Abstract* – Testing of the range and radiation pattern of wireless sensors is often not fully documented. In this paper, we perform a full characterization of the Tmote Sky motes from MoteIV Corporation. Packet yield, RSSI, and LQI are measured as a function of distance, angle, and transmit power, while taking environmental conditions into consideration. We aim to present a set of guidelines for setting up Wireless Sensor Networks that will enable them to achieve their QoS goals and maximum lifetime. Initial results show that the radio antenna pattern on the Tmote Sky device is not truly omnidirectional, that RSSI and LQI do not degrade solely as a polynomial function of distance, and that transmitting and receiving node heights have a major impact on link performance.**

## I. INTRODUCTION

Performance is very important in Wireless Sensor Networks (WSN). Individual nodes in a WSN have a limited amount of energy, and how to best use this limited energy is a major research topic. Characterizing link behavior is necessary so that the networking protocols can be most effective. Furthermore, when deploying sensors into a target field, information about how sensors perform at various distances and orientations relative to each other will make optimal placement easier. If each node is placed to maximize its performance in the network, which is possible for small to medium sized networks, the lifetime and quality of service for the entire network will increase.

Many sensor nodes have radios that claim to be omnidirectional, meaning they can transmit equally in all directions. This claim is not completely accurate, as the antennas have weaker and stronger reception areas in 3D space. The quality of a link is dependent upon several parameters, including angle and distance.

This project aims to characterize the radiation pattern characteristics of the Tmote Sky motes from the MoteIV Corporation (www.moteiv.com). The indicators of performance we use are packet loss rate, Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). By analyzing these with respect to distance, angle, and 3D orientation, we will present a clear picture of the actual capabilities of the Tmote Sky motes. The effects of weather, time of day, humidity, light and transmit power on these link metrics will also be investigated. We further analyze both the forward and reverse channels in order to characterize the links as symmetric or asymmetric. Based on our results, we will provide suggestions as to how to place nodes in a real sensor network so as to maximize performance.

## II. EXPERIMENTAL METHODS

### *A. Programming*

The motes are programmed using nesC (nested C) in the operating system TinyOS. TinyOS is used in many implementations of WSNs. The experiment is set up with one base station mote, one pinging mote, and 20 response node motes. The pinging mote sends out a ping requesting a response from the 20 nodes. The response nodes measure the ping's RSSI and LQI. Each response node then sends a reply message after a delay that is a function of its node ID, ensuring no collisions among response messages. The data in the message contains all RSSI and LQI information, as well as information about the response node's transmit power, internal voltage, humidity, temperature, and light readings. These readings are taken from the sensors on board the motes.

The pinging mote receives messages from the 20 response nodes one at a time. As it receives each message, it measures RSSI and LQI, and then it sends out a complete data message with all the data from the response node as well as these additional reverse channel measurements to the base station mote.

### *B. Physical Setup*

The pinging mote is situated atop a tripod, which is placed at various heights throughout the experiment. The base station sits next to the tripod on the ground. At this close distance, the base station can hear all messages sent from the pinging mote. A tape measure extends out from the base of the tripod in a straight line, and response nodes are placed every 5 feet. When the experiment begins, a reset button is pressed on the pinging mote, which starts a series of 30 pings at 3 different power levels. Once these pings have been sent and the data received at the base station, the pinging mote is rotated 45 degrees. The pinging sequence runs 16 times, twice for each 45 degree spacing.

## III. INITIAL RESULTS

We have run 7 sets of experiments in an outdoor environment, with 20 data points for each (distance-angle-transmit power) combination per experiment, and we average all 140 data points to obtain the plots shown here. Three different transmit powers were used in these experiments—out of a maximum of 31 for transmit power, we tested low transmit power (value=11), medium transmit power (value=21) and high transmit power (value=31). Results for packet yield are plotted in Figure 1 for high transmit power, Figure 2 for medium transmit power, and Figure 3 for low transmit power. Figures 4 and 5 show RSSI and LQI, respectively, as a function of distance and angle at the highest transmit power. The RSSI and LQI values are shown as measured from the pinging mote to the response nodes (forward channel). For all of these data, the tripod with the pinging mote is set at 42 inches from the ground.

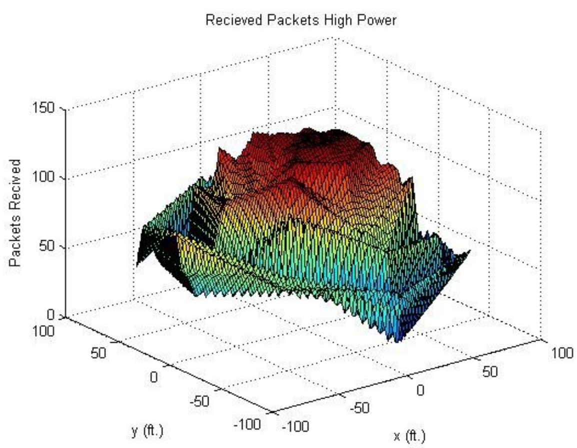


Figure 1. Packet yield vs. distance and angle at high transmit power.

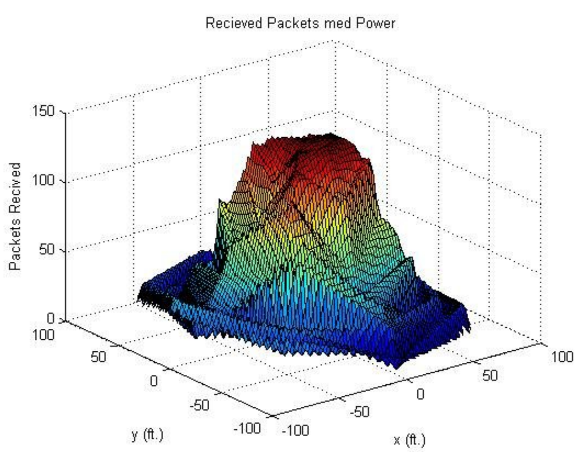


Figure 2. Packet yield vs. distance and angle at medium transmit power.

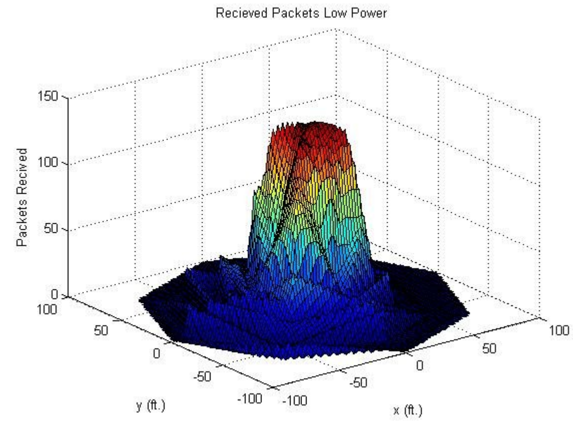


Figure 3. Packet yield vs. distance and angle at low transmit power.

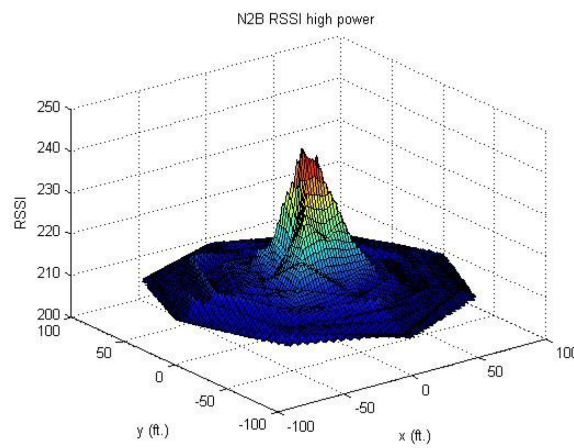


Figure 4. RSSI vs. distance and angle from the pinging mote to the response nodes for high transmit power.

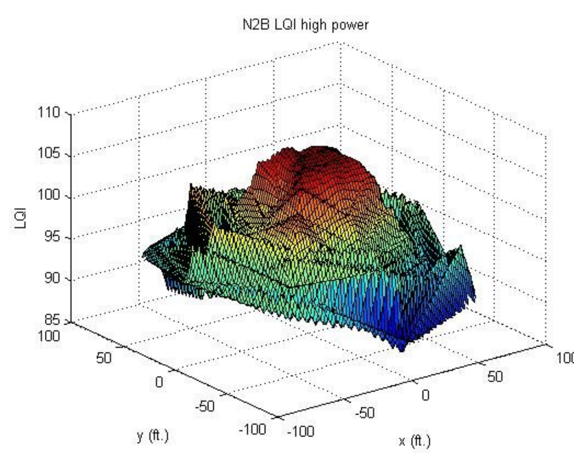


Figure 5. LQI vs. distance and angle from the pinging mote to the response nodes for high transmit power.

A sample plot of RSSI with error bars at an angle of $0^o$ shows that RSSI has a very small range of error (Figure

6), and thus we can draw some statistically reliable conclusions from this data. On the other hand, LQI shows a much higher range of error (Figure 7). Further statistical analysis will be performed when more data is obtained.

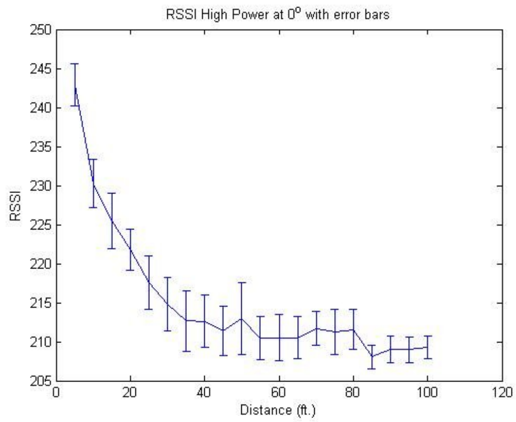


Figure 6. RSSI vs. distance at $0^o$ from the pinging mote to the response nodes with error bars.

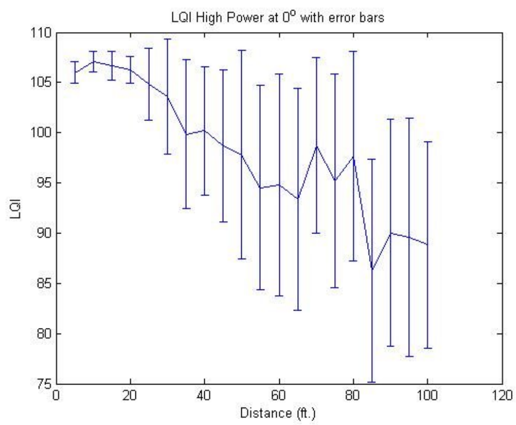


Figure 7. LQI vs. distance at $0^o$ from the pinging mote to the response nodes with error bars.

## IV. DISCUSSION

The packet yield as a function of angle corresponds closely to the antenna radiation pattern provided in the datasheet for the Tmote Sky motes [2]. Packet yield also drops off at lower transmit powers, which is to be expected. However, we have found that packet yield as a function of distance depends very heavily on the height of both the sending and receiving motes. When two motes were placed directly on the ground, their range was only about 45 feet. With one mote raised and one on the ground we are able to receive data from 100 feet. With both motes raised off the ground we are able to receive data from over 150 feet. These results emphasize the importance of node placement. In most situations sensor nodes will have to be deployed on walls and floors, where they will not be able to achieve their full range. A network designer should keep this in mind when deciding how many nodes should be used to cover a given area. In initial indoor tests, the claim of 30m indoor range is verified, although no walls or significant barriers were placed in the line of sight from the pinging node to the response nodes.

A curious result of these initial data is the shape of the RSSI vs. distance plot. The plot falls at a fast rate close to the transmitter, and then flattens out for the rest of the field. After researching this phenomenon, we found that beyond the point of high packet yield, the signal to noise ratio degrades to the minimum sensitivity of the mote, causing RSSI to appear flat [1]. LQI appears as expected, with a linear drop off until the threshold is reached. Another observation is that LQI seems to be quite a good indicator of packet yield, as we see a strong correlation between LQI and packet yield for similar experiments.

## V. RELATED WORK

When Telos Revision B was released, testing was done to approximate RSSI, LQI, and packet yield as a function of distance. Our results are thus far consistent with the findings in this study [1]. Polastre et al. drew the same conclusion about RSSI values, and had similar peaks and valleys in LQI and packet yield functions.

## VI. CONCLUSIONS AND FURTHER WORK

In the early stages of this project, a better picture of the performance of these motes is already emerging. Some surprising results have shown this work to be non-trivial. The leveling out of RSSI beyond a certain distance suggests that it should not be used to indicate distance between motes beyond this threshold distance. In general, a close inspection of a sensor's radiation pattern may be required before deploying a WSN. Once a complete picture of the field around these motes' antennas is obtained, setting up real networks with the Tmote Sky motes will become more straightforward and able to achieve better performance.

Once more data sets have been recorded, both indoors and outdoors, additional environmental factors such as weather, humidity, and brightness will be analyzed for their effects on RSSI, LQI and packet yield. Regression will be performed in order to determine whether or not there is a correlation between any of these variables and the overall performance of the system.

## REFERENCES

[1] Joseph Polastre, Robert Szewczyk, and David Culler, "Telos: Enabling Ultra-Low Power Wireless Research," IPSN/SPOTS, Los Angeles, CA, April 25-27, 2005.

[2] MoteIV Corporation, "Telos (Rev B) Datasheet," http://www.moteiv.com, Dec. 2004.