Empirical Robustness Analysis of Wireless Connectivity in Sensor Network Deployments

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Abstract

Health care is a prospective area for using low power, wireless sensors. Elderly people can ask for remote assistance with the help of wireless sensor networks and stay at home with comfort and added security. In this project I empirically analyzed the robustness of wireless connectivity in sensor network deployments. Besides the connectivity issue, I also provided some general guidelines for deploying sensors in a typical household setting. I evaluated the wireless connectivity of triangular, rectangular, square and random deployment patterns. Then, by changing the radio frequency power level of the nodes, I measured the variation in wireless connectivity using the link quality indicator, the packet reception rate, and the yield for each node. I found out from my experiments using tmote sky sensor nodes in the different deployment patterns that the wireless connectivity of the nodes does not vary significantly in a typical room of $\approx$*7.08 meter* $\times$ *3.29 meter* $(l \times w)$*. The nodes have an overall good yield, link quality, and packet reception rate at any place in the room.*

1 Introduction

Wireless sensor networks have become a good choice for real world applications such as habitat monitoring, object tracking, fire detection, traffic monitoring, seismic detection, etc [2] [9]. Health care is a prospective area for using low power wireless sensors. According to the US Administration on Aging, the number of persons aged 60 years or older is projected to grow to almost 2 billion globally by 2050. As the number of elderly people increase, the medical cost will also increase proportionately. They do not want to go to nursing homes and prefer to stay at home. Wireless sensor networks can thus be used to provide comfort, security and daily monitoring of the elderly people's activities. With the help of wireless sensor networks, elderly people can ask for remote help. Their relatives can also be alerted when something serious happens.

Researchers have proposed different deployment patterns and methods to compute the optimal number of sensor nodes to detect a target. Researchers also tested the wireless connectivity of sensor nodes using different types of sensor nodes (i.e. micaZ, tmote sky) in indoor and outdoor settings. Despite these efforts, there is not enough data that provide general guidelines for deploying sensors and the quality of wireless connectivity in a household setting.

In this paper, I empirically analyze the robustness of wireless connectivity of wireless sensor network deployments in a typical household setting. I first define different patterns such as triangular, rectangular, square, random, etc. for deploying sensor nodes in a $\approx$7.08 meter $\times$ 3.29 meter room. Then, to analyze the variation in connectivity, I observe how varying the radio frequency power level affects the link quality, yield and packet reception rate of the nodes. From my experiments I have found that the wireless connectivity does not vary significantly in a typical household setting with respect to different deployment patterns and heights of sensor nodes from the ground.

2 Experimental Methodology

1. Platform

In order to analyze the wireless connectivity of sensor nodes in a typical household setting, I used tmote sky sensor nodes. I used 6 tmote sky sensor nodes in my experiments. The tmote sky has a Chipcon CC2420 radio transceiver, which also allows the user to change the radio frequency power level from 0 dBm(RF power level 31) to -25 dBm(RF power level 3) [6].

Figure 1. tmote sky sensor module [6]

I used the TinyOS platform and the `Surge` program [5], a sample application in TinyOS which uses `MultiHopLQI` multihop ad-hoc routing [3]. `Surge` is designed to be used in conjunction with the `Surge` java tool. `MultiHopLQI` provides the value for link quality indication. The `Surge` java tool has a class named `MainClass` which processes the sensor data from the `Surge` programmed nodes [4]. The java applet snoops the multihop headers to provide a graphical view of the sensor network topology [5].

2. Performance Metrics

For the experiments, I measure the following performance metrics: yield, link quality indication and packet reception rate.

Yield: Yield is calculated in the `SensorAnalyzer` class of the `Surge` java tool. At first, the difference between the current time and the last time a packet was received is calculated and compared with the average time interval which is set to 5000 millisecond. If the difference is greater than the average time interval, the variable `lastMsgCount`, which keeps track of the number of packet received is divided by the time difference, and this gives the message rate. The message rate is then multiplied by the sample rate, which is set to 2048 and also means that every 2 seconds a message with sensor data is transmitted from each node. After that the `lastMsgCount` variable is reset to zero(0).

Link Quality Indication (LQI): Link Quality Indication is a characterization of the strength and/or quality of a received packet as defined by the IEEE standard 802.15.4 [1]. It can also be viewed as chip error rate and is calculated over 8 bits following the start frame delimiter (SFD). LQI values are usually between 110 and 50 and correspond to maximum and minimum quality frames respectively [11].

Packet Reception Rate (PRR): The packet reception rate is calculated from the packet sequence numbers. The `Surge` message has a sequence number field inside in it which is used to see how many messages have been passed through the base station. The missing sequence number indicates that a message corresponding to it has been lost. The total number of messages that has been received successfully is divided by the total number of messages considered, and multiplying the result by 100, the PRR is calculated.

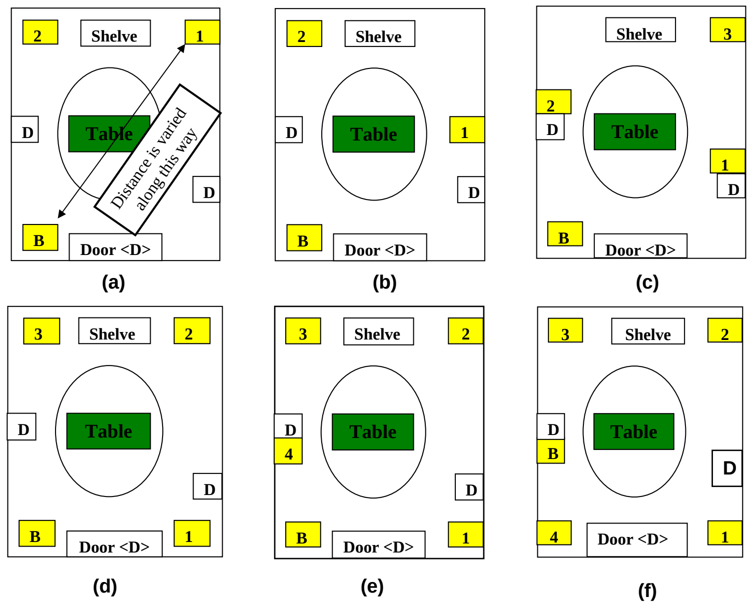

Figure 2. Sensor deployment patterns: (a) and (b)Triangular (c)Parallelogram (d),(e) and (f) Rectangular [These patterns were inspired by the discussion on deployment patterns in [8] [10] [12]]

3 Experiment Results

1. Experiment Configurations

I performed my experiments in a ≈7.08 meter × 3.29 meter room. However, before starting my experiments I tested the range of a tmote sky sensor node in a hall way. I found that with the lowest power level, a tmote sky sensor node has a maximum range of ≈11 meter. During the experiments, I placed the sensors in the room according to the patterns shown in Fig. 2 and Fig. 3. Before gathering the data, I set the RF power level of all the nodes to 3. I recorded the node ID, link quality value, yield and the sequence number for each message. I collected 100-120 messages from each node. Occasionally, I changed the RF power level to 7 to see the effect on the parameters that I was recording. I used a maximum of 6 nodes including the base station for my experiments.

2. Observation

In the setting depicted in Fig. 2(a), I changed the distance between the base station and node 1 along the diagonal of the room. I placed node 1 at the middle of the room which was ≈3.57 meter far from the base station and ≈3.18 meter from node 2. At that position, node 1 had a good average yield (90-100) with an acceptable average LQI of ≈90 [Fig. 4(a)]. At the far end (distance between base station and node 1 was ≈6.7 meter), node 1 had ≈85-90% yield as well as an average LQI of ≈85 [Fig. 4(b)]. As the distance increased, the avg. yield of node 1 deteriorated with a slight decrease in the avg. LQI. It seems that the yield and LQI vary with distance. I think more study is required to analyze the issue.

In the setting depicted in Fig. 2(b), a person walked around the room and stopped in front of the sensor nodes. Both nodes 1 and 2 had a good average LQI (100-110) but node 2 had a average yield of ≈80-85%

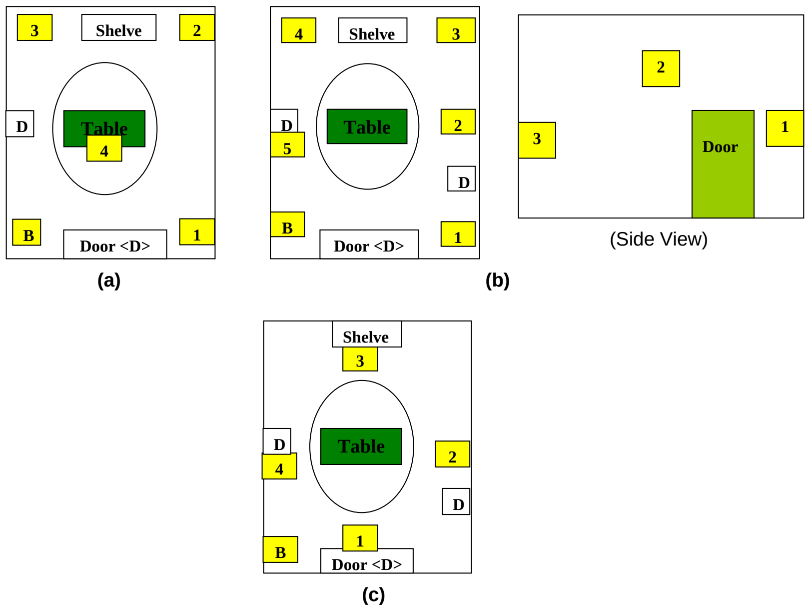

Figure 3. Sensor deployment patterns: (a) Random (Nodes do not represent actual placement) (b)Rectangular with side view (c) Random [Nodes do not represent actual placement. These patterns were inspired by the discussion on deployment patterns in [8] [10] [12]]

while node 1 had a ≈95% yield [Fig. 4(c)]. On the other hand, when there was nobody walking around the room, both node 1 and 2 had a good average yield (90-100) but node 2 had a lower average LQI compared to node 1 [Fig. 4(d)]. I believe the lower yield in the first situation was because the person stopped in front of node 2 for a longer period than node 1 and also the distance between the base station and node 2 was larger than the distance between the base station and node 1. In the second situation, the distance may be the cause for a low LQI of node 2 compared to the LQI of node 1 even though the yield was almost 98%.

In the setting depicted in Fig. 2(c), when the RF power level was set to 3, nodes 1, 2 and 3 had a good average yield but node 2 had a slightly lower LQI than the other 2 nodes [Fig. 5(a)]. In this case, I placed node 2 vertically which also changed the orientation of radio wave propagation and thus affecting the LQI. However, when the RF power level was set to 7, the average LQI for node 3 deteriorated but still had a satisfactory average yield [Fig. 5(b)]. When the RF power level was 3, node 3 had a good avg. yield while with a high power level it had a low LQI compared to the previous experiment. I think this issue may need to be revisited more carefully later on. Later, the RF power level was set to 3 and two foam boards were placed in front of node 2 and 3. In that position, node 3 had an average LQI of 95-100 [Fig. 5(c)]. In this case the distance and obstruction might have affected the LQI.

For the rectangular pattern in Fig. 2(d), nodes 2 and 3 had a slightly lower LQI compared to node 1 but node 1 had a slightly lower average yield than the other 2 nodes [Fig. 5(d)]. However, gradually over time the average LQI improved for nodes 2 and 3 with an increase in the average yield for node 1. The network appears to stabilize with the passage of time.

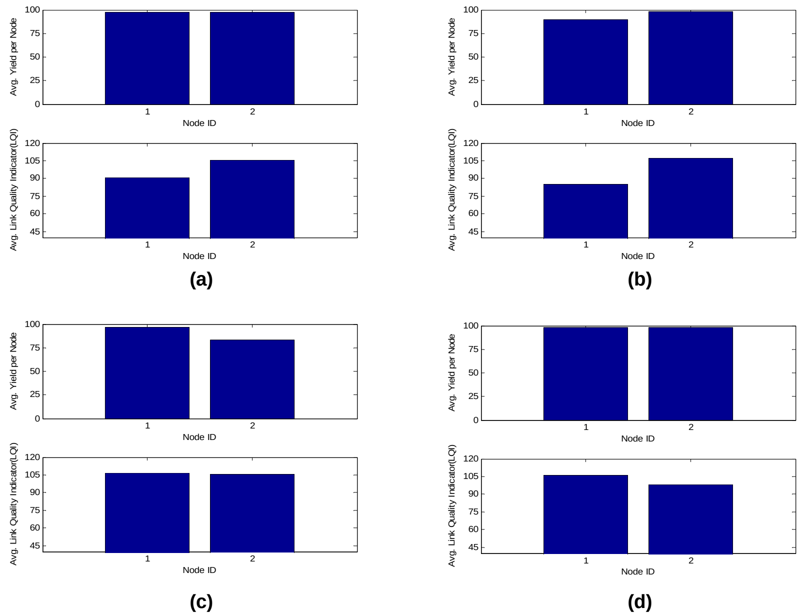

Figure 4. Output results with node ID, average LQI and average Yield (Corresponds to Fig. 2 (a), (a), (b) and (b))

In the setting depicted in Fig. 2(e), a new node was introduced between the base station and node 3. Node 4 was placed 1.90 meter apart from the base station. This setting performed well [Fig. 6(a)]. However, when the position between the base station and node 4 flipped as shown in Fig. 2(f), the average LQI of node 2 and 4 dropped slightly below the LQI of the other 2 nodes [Fig. 6(b)]. Switching the base station and node 4 might have made the system unstable which in turn affected the LQI.

In all the previous settings, all the nodes including the base station was placed at a height of ≈1.02 meter.

In the setting depicted in Fig. 3(a), node 4 was placed at a height of ≈2.62 meter from the ground. All the other nodes including the base station were at a height of ≈1.02 meter from the ground. Even though one node was placed at a higher level than the others, the performance of the overall network did not deteriorate significantly. The only performance degradation was that node 1 had an average yield of ≈85-90% instead of $\geq$ 95% even though it had a good LQI [Fig. 6(c)].

Next, a new node was introduced and the sensors were deployed as shown in Fig. 3(b). Nodes 2 and 5 were placed at a height of ≈2.19 meter while the other nodes were placed at a height of ≈1.02 meter. There was a variation in the average LQI of the nodes while the average yield was satisfactory. Nodes 1 and 2 had the same average LQI ≈(95-100). Nodes 3 and 5 also had the same average LQI ranging between ≈104-105 [Fig. 6(d)]. It is unusual that even though all the nodes were at the same height, the LQI for all the nodes varied from each other. Traffic congestion might have caused the difference in LQI between the nodes.

In the last setting i.e. according to Fig. 3(c), nodes 1, 2 ,3 and 4 were placed at a height of ≈2.19 meter while the base station was placed at the same height of ≈ 1.02 m. In that setting, all the nodes had a good average yield and LQI except node 4 had an average LQI. Node 4 had an avg. LQI of ≈92-95 [Fig. 7(a)] but

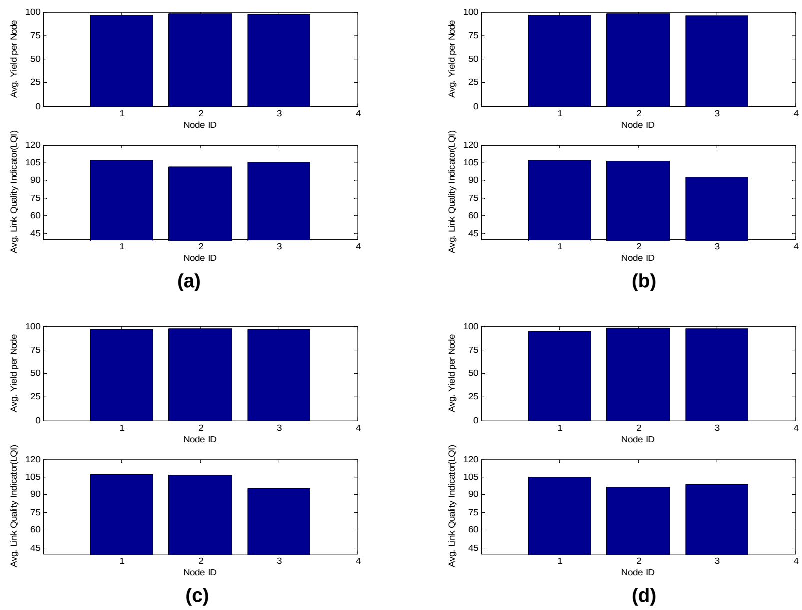

Figure 5. Output results with node ID, average LQI and average Yield (Corresponds to Fig. 2 (c), (c), (c) and (d))

still had a good avg. yield. With this setting I placed an extra node outside the room to see if the sensor nodes are able to penetrate the doors and walls. The 5th node was placed at a distance of ≈1.65 meter from the door. The sensors were not able to communicate with the node lying outside in the ground at a RF power level of 3. When the RF power level was gradually increased from 3 to 11, the sensor node could communicate with the other sensor nodes inside the room.

However, in all the settings it was observed that though the average LQI of the nodes was low, their yield was high or vice versa. The function `MacControl.enableAck()` is used in the `Surge` program, which actually enables the retransmission capability of the messages. I disabled the `MacControl` function to see the effect on the overall performance of the network and found out that node 2 had an average LQI of 85 and a ≈80-85% average yield [Fig. 7(b)] for the setting in Fig. 2(c). Apparently, retransmission of packets is crucial for maintaining good connectivity in the network.

The packet reception rate of the nodes in different settings was satisfactory except for setting Fig. 2(c) when the `MacControl` function was disabled. Node 2 in that case had a very low PRR, which is usual. Fig. 7(c) shows the PRR for the setting in Fig. 3(b).

4 Conclusion

From the experiments, it seems that in a typical room of a house the wireless connectivity does not vary significantly with node placement for the tmote sky sensor mote. The different deployment patterns do not affect the overall connectivity of the sensor nodes. Even at a low radio frequency power level, the sensor nodes are able to communicate with each other. In my experiments I kept the radio frequency power level to 3, only

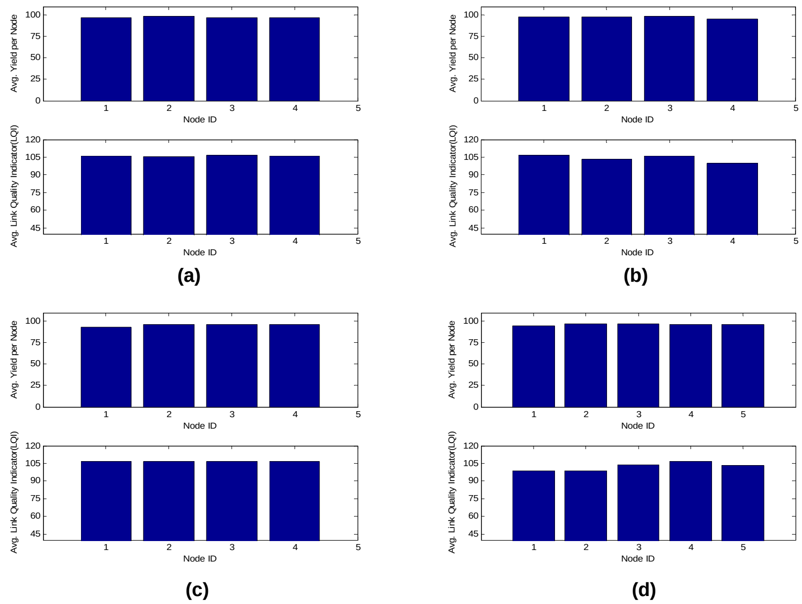

Figure 6. Output results with node ID, average LQI and average Yield (Corresponds to Fig. 2 (e) and (f) and Fig. 3 (a) and (b))

changing it to 7 in 2 or 3 experiments because at RF power level 3, we can minimize the power consumption. The current consumption at RF power level 3 (8.5mA) is almost half of the full power level (17.4 mA) [6].

5 Future Work

In my experiments, I have considered only some parameters to analyze the wireless connectivity. I also think that LQI by itself may not be adequate for predicting the wireless connectivity. The next step in this research project is to:

1. Include Received Signal Strength Indicator (RSSI) in the experiments [7] [11]
2. Evaluate the sensor deployments patterns proposed by other researchers
3. Perform experiments in larger rooms and in residential houses to better understand wireless connectivity and optimal sensor deployment patterns.

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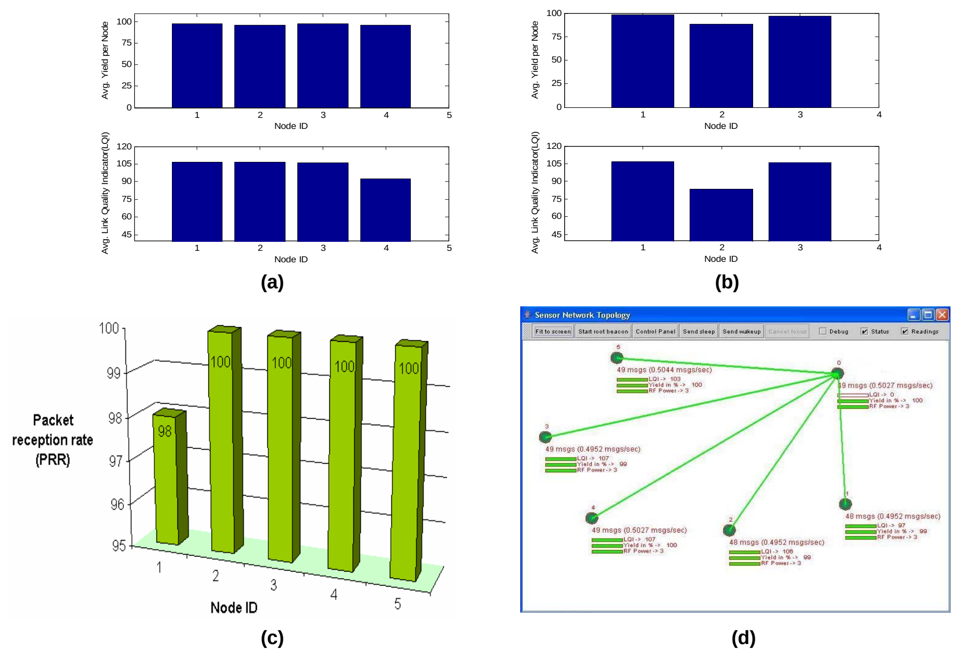

Figure 7. (a) (b) Output results with node ID, average LQI and average Yield [Corresponds to Fig. 3 (c) and Fig. 2(c)] (c) Packet reception rate with node ID and (d) SURGE GUI for setting Fig. 3(b)

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