Using Received Signal Strength Variation for Energy Efficient Data Dissemination in Wireless Sensor Networks

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Abstract— **In this paper, the values of received signal strength indicator (RSSI) are studied for various deployment environments in wireless sensor networks. The accurate RSSI estimation can improve the accuracy of several algorithms used in localization, mobility, and routing. The experiments are conducted to investigate the variation in RSSI values with respect to: a) distance between transmitter and receiver, b) non-circular radio communication, and c) alignment of transmitter and receiver. The results show that because of a non-circular radio communication model and proper alignment techniques, the overall energy consumption of a sensor network can be reduced by 43%.**

I. Introduction

Due to recent developments in electronics, wireless sensors are commonly used for ubiquitous and pervasive applications. For example, sensors networks are used in military, security, health-care [1], environment and habitat monitoring [2], [3]. Further, as computing, storage, and communication resources are very limited for current available sensors, there is a need for energy efficient algorithms and techniques to provide scalable solutions [4].

In sensor devices there are some irregularities in radio range in different directions [5], [6], [7], [8], [9]. Zhou et al. [5] investigate degree of variation in RSSI values and propose a non-circular radio irregularity model (RIM) for sensor networks. Gallais et al. [10] discuss the effect of a realistic radio channel on area coverage protocols. Scott et al. [11] use transmit and receive signal strengths to investigate propagation patterns.

We investigate radio irregularity with respect to distance, sending power level, direction, and alignment of the sensor node from the base station. The experimental results show that proper alignment and sending power level can reduce the energy consumption, in order to increase the network lifetime.

The remaining paper is organized as follows: Section II provides the details for realistic radio communication. Section III gives the experimental results for RSSI investigation. Section IV describes an application of RSSI variation for energy efficient localization. Finally, Section V concludes the paper and provides directions for future work.

II. Realistic Radio Communication

In this section we describe a few terms that would be needed in the investigation of RSSI values.

Definition 1: Direction is defined as the angle with respect to geographical direction, where North, East, South, and West are considered as 0, 90, 180, and 270 respectively.

Direction is used to identify the physical location of a node with respect to a given node. Figure 1 illustrates some of the examples where a node can be placed. For instance, Figure 1(a) shows that a node is placed at North direction with respect to the base station. Similarly, Figure 1(b), Figure 1(c), and Figure 1(d) show that nodes are placed at East, South, and West directions respectively. Further, we can use angle to identify the location. The angle starts from North direction and continues in clockwise direction. For example, the directions of nodes placed at North, East, South, and West can be represented as 0, 90, 180, and 270.

Definition 2: Alignment is defined as the angle between the two motes.

Figure 2 shows different alignments for a sensor mote. The sensor mote shown in Figure 2(a), Figure 2(b), Figure 2(c), and Figure 2(d) are at alignments 0, 90, 180, and 270 respectively. It should noted that direction in all cases is same, which is North direction; however, the alignment is different for all the cases.

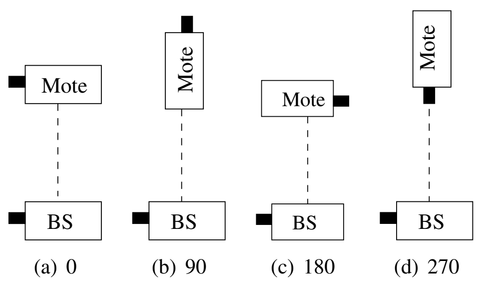
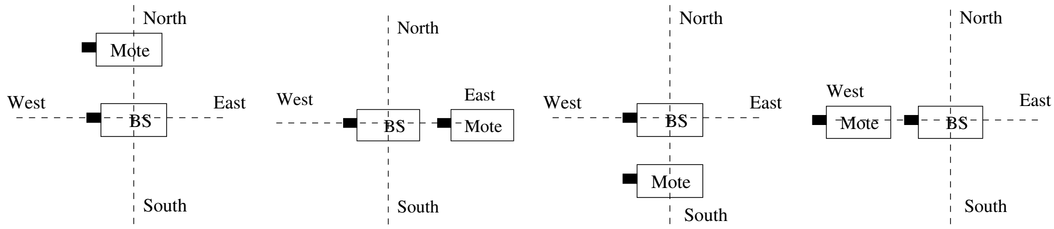


Fig. 2. Alignment of sensor motes: 0, 90, 180, and 270.



(a) Direction North (b) Direction East (c) Direction South (d) Direction West

Fig. 1. Directions for node placements: North (0), East (90), South (180) and West (270).

Definition 3: Distance is as defined as a Euclidean distance between two motes.

Although distance is commonly used in simplified RSSI estimation, the accurate scaling factor or correlation of RSSI with respect to distance is very challenging. For instance, in many radio communication models, energy consumption is considered as directly proportional to the square of distance (circular model) [12]; however, it is not applicable in most of the realistic environments.

III. Experiments

Experiments are conducted in an indoor environment using Moteiv's Tmote Sky [13] sensor motes. The variation in RSSI values is investigated for direction, alignment, and distance. Further, the experiments are conducted in different locations to validate the results.

A. *RSSI Variation with respect to direction*

In this experiment, the variation in RSSI values is investigated with respect to direction. The base station is fixed at a specific location and the other mote is moved in four directions: North, East, South, and West. The experiment details are as follows: the distance between sensor mote and base station is fixed as 10 feet, the sending power level is 10, for each experiment 100 packets are transmitted.

Figure 3(a) shows the signal strength variation in North direction. Similarly, Figure 3(b), Figure 3(c), and Figure 3(d) show the signal strength variation in East, South, and West directions respectively. The x-axis shows the message (packet) sequence numbers and y-axis shows the RSSI values. The observations from the experiment are as follows: a) RSSI varies for different packets in the same direction, which shows temporal variation in RSSI, b) average and standard deviation values of RSSI is different for each direction, which shows spatial variation in RSSI.

B. *RSSI variation with respect to alignment*

In this experiment, the effect of alignment on RSSI values is investigated. The experimental details are as follows: a) the direction of sensor mote is fixed at North, b) distance is 5 feet, c) sending power levels are 5, 10, 15, and 20, d) alignments are 0, 90, 180, 270, and e) 50 samples are taken for each configuration.

TABLE I

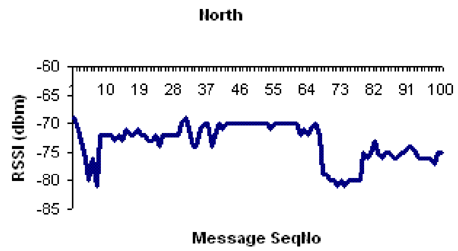
RSSI variation for different alignments for distance 5 feet and direction North.

align.	Location	Sending Power Levels			
		5	*10*	*15*	*20*
0	Avg	-61.91	-57.2	-52.48	-46.74
	Max	-60	-57	-50	-46
	Min	-63	-58	-53	-47
	Var.	0.1974	0.16	0.5696	0.1924
90	Avg	-64	-55.56	-55.3	-51.86
	Max	-62	-55	-53	-48
	Min	-65	-58	-57	-53
	Var.	0.163	0.846	0.97	1.720
180	Avg	-61.18	-56.36	-51.2	-45.2
	Max	-60	-56	-49	-45
	Min	-63	-57	-52	-46
	Var.	0.3948	0.230	0.8	0.16
270	Avg	-59.14	-53.84	-47.26	-44.36
	Max	-56	-52	-46	-43
	Min	-60	-55	-50	-45
	Var.	1.102	0.454	0.632	0.390

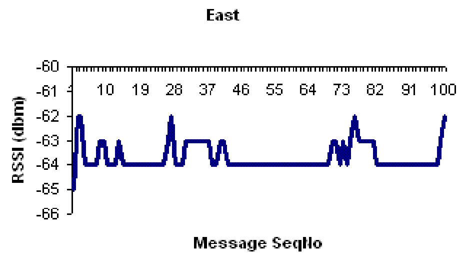
Table I shows the variation in RSSI with respect to alignment. For alignment 0, the values of variance in RSSI are small, which shows that estimated RSSI values will be more accurate. However, the values of variance for alignments 90 and 270 are high, which shows that the estimated RSSI values will not be accurate. Further, for alignment 90, the value of variance for sending power level 20 is relatively higher than the variance for other power levels. On the other hand, for alignment 270, the higher value of variance (1.102) is measured at lower sending power level (5). It means that, even for the same alignment, there could be variation in variance for different power levels.

Observation: For the same distance and power level, it is possible to get significant variation in RSSI values because of different alignments.

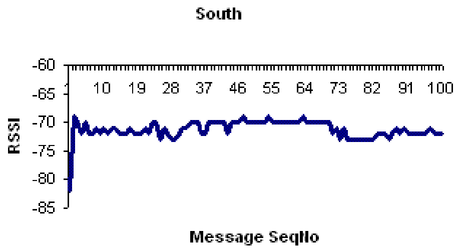
For example, for distance of 5 feet and sending power level of 20, 30% change in RSSI values is obtained for alignment



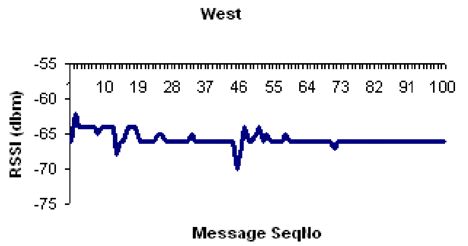
(a) Signal Strength Values in North Direction



(b) Signal Strength Values in East Direction



(c) Signal Strength Values in South Direction



(d) Signal Strength Values in West Direction

Fig. 3. Signal strength variations in 4 directions: North, South, East and West.

180 with respect to alignment 90.

C. RSSI variation with respect to location

As RSSI variation depends on deployment environment, an experiment is conducted to investigate the RSSI variation for different deployment locations. The distance between base station and the sensor mote is fixed at 20 feet, as well as the direction of sensor mote with respect to base station is North. However, the base station and sensor mote are deployed in two different locations and the RSSI values are obtained for four alignments: 0, 90, 180, and 270. Further, for each alignment experiment, the RSSI value is the average of 100 values.

TABLE II
RSSI VARIATION FOR DIFFERENT LOCATIONS FOR LONGER DISTANCES (20 FEET).

align.	Location	Sending Power Levels			
		5	*10*	*15*	*20*
0	1	-80.06	-74.06	-68.54	-65.04
	2	-81.53	-76.5	-69	-65.49
90	1	-79.48	-73.5	-65.72	-62.1
	2	-72.76	-65.12	-60.14	-54.42
180	1	-74.36	-68.26	-63.82	-60
	2	-76.18	-69.34	-62.08	-58.22
270	1	-74.76	-70.64	-66.42	-62.06
	2	-80.34	-75.52	-70.98	-66.68

Table II shows that the variation in RSSI values because of alignment is observed in both locations. For instance, for location 2, RSSI values are -65.49 dBm and -65.12 dBm for alignments 0 and 90 with power levels of 20 and 10 respectively. Similarly, for location 1, the RSSI value (-74.36 dBm) for sending power level of 5 for alignment 180 is almost same as RSSI value (-74.06 dBm) for sending power level of 10 for alignment 0, which shows that identical RSSI values could be obtained for lower sending power levels because of proper alignment.

TABLE III
RSSI VARIATION FOR DIFFERENT LOCATIONS FOR SHORTER DISTANCE (5 FEET).

align.	Location	Sending Power Levels			
		5	*10*	*15*	*20*
0	1	-61.91	-57.2	-52.48	-46.74
	2	-65.58	-59.86	-55.32	-52.64
90	1	-64	-55.56	-55.3	-51.86
	2	-74.1	-64.52	-57.4	-56.44
180	1	-61.18	-56.36	-51.2	-45.2
	2	-60.40	-54.86	-47.18	-43
270	1	-59.14	-53.84	-47.26	-44.36
	2	-61.86	-56.34	-51.46	-46.3

In the second experiment, the alignment variation with respect to a location was investigated for shorter distances (5 feet). Table III shows RSSI variations with respect to alignment, where distance between sensor node and base station is 5 feet. As shown in Table III, the variation in RSSI values because of alignment is also observed for shorter distances. For instance, for location 2 and sending power level 5, RSSI values are -65.58 dBm and -74.1 dBm for alignments 0 and 90 respectively, which shows that RSSI values could significantly vary with respect to alignment. Thus, the results from Table II and Table III confirm that there is variation in RSSI values with respect to alignment, even for different locations.

D. RSSI variation with respect to distance

Another experiment is conducted to investigate the variation in RSSI with respect to alignment for different distances. The direction of the sensor node to the base station is fixed for all the cases, and the alignment is varied as 0, 90, 180, and 270, as shown in Figure 2. The experiment details are as follows: a) the distance (feet) between sensor mote and base station is varied as 5, 10, 15, 20, and 25, b) sending power level is varied as 5, 10, 15, and 20, c) for each experiment 50 packets are transmitted, and d) the average RSSI of 50 received messages is recorded.

Figure 4 shows the results of the above experiment. The results in Figure 4 confirm the variation in RSSI values with respect to alignment for different distances. As expected, as distance to the base station increases, the RSSI value decreases; however, for all distances, a significant variation in RSSI values because of alignment is observed. The sending energy can be reduced by proper alignment. For example, in Figure 4, for distance of 5 feet, the RSSI value (-54.86 dBm) for sending power level of 10 for alignment 180 is higher as compared to RSSI value (-56.44 dBm) of sending power level of 20 for alignment 90. In other words, because of proper alignment, identical RSSI values can be obtained by only using half the sending power level.

IV. APPLICATION

The RSSI variation with respect to alignment and sending power level are considered in measuring the power consumption for different cases. As RSSI values vary with respect to direction, distance, alignment and sending power level, two scenarios are created where the expected RSSI is same but the sending power levels are different; the experimental scenarios are as follows:

- *Scenario 1:* For location 2, where sending power level is 10, alignment is 90, the expected RSSI is -65.12 dBm, Table II.
- *Scenario 2:* For location 2, sending power level is 20, alignment is 270, the expected RSSI is -66.68 dBm, Table II.

For both scenarios, the distance between base station and sensor mote is 20 feet and the direction of sensor mote is North of base station. The RSSI values are obtained from Table II. The residual voltage is measured after successful tranmission of 3600 packets.

Although sending power level of Scenario 1 is less than the sending power level of Scenario 2, the average RSSI value of Scenario 1 is better than the average RSSI value of Scenario 2. As a reminder, the energy efficiency in Scenario 1 is because of proper alignment, which is specific to the deployment environment.

Table IV shows the results of the experiment and some of the observations are as follows:

1) Battery consumption can be significantly reduced for larger packets. For instance, for 100-byte packets, the power consumption in Scenario 1 is 57% of the power consumption in Scenario 2. In other words, 43% power savings can be obtained because of proper alignment. Further, the 43% power savings are obtained without compromising the RSSI quality.
2) Power savings are relatively insignificant for smaller packets. For example, for 10-byte packets, the power consumption in Scenario 1 is 75% of the power consumption in Scenario 2.

V. CONCLUSION

In this paper, we conducted experiments with Moteiv's Tmote Sky motes to investigate RSSI variation with respect to: a) direction, b) distance, and c) alignment from the base station. Further, the variation is confirmed for different locations and for several sending power levels. Finally, as an application, an experiment was conducted to show that proper alignment can reduce overall energy consumption. For smaller packets (10 Bytes), 25% power savings can be obtained; however, for larger packets (100 Bytes), 43% power savings were observed.

In future, we would like to investigate the accuracy of mobility and localization algorithms using more comprehensive radio communication characteristics such as direction, distance, and alignment of sensor nodes. Further, these localization and mobility techniques can be used for various applications such as remote health care, smart homes, and industrial automation.

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distance	Sending Power Levels			
	5	*10*	*15*	*20*
5	-65.58	-59.86	-55.32	-52.64
10	-72.24	-68.18	-60.43	-57.82
15	-75.73	-67.7	-62.84	-58.5
20	-80.06	-74.06	-68.54	-65.04
25	-72.79	-65.94	-60.94	-57.3

(a) 0

distance	Sending Power Levels			
	5	*10*	*15*	*20*
5	-74.1	-64.52	-57.4	-56.44
10	-77.6	-69.76	-63.94	-61.12
15	-76.55	-70	-64	-60.48
20	-79.48	-73.5	-65.72	-62.1
25	-68.44	-62.04	-55.42	-54.40

(b) 90

distance	Sending Power Levels			
	5	*10*	*15*	*20*
5	-60.40	-54.86	-47.18	-43
10	-67.08	-60.4	-56.94	-53.22
15	-73.83	-67.57	-62.36	-57.56
20	-74.36	-68.26	-63.82	-60
25	-73.40	-66.02	-60.42	-58.38

(c) 180

distance	Sending Power Levels			
	5	*10*	*15*	*20*
5	-61.86	-56.34	-51.46	-46.3
10	-76.94	-69.34	-69.22	-67.78
15	-71.93	-63.46	-57.48	-57.24
20	-74.76	-70.64	-66.42	-62.06
25	-71.04	-63.54	-59.96	-56.36

(d) 270

Fig. 4. Alignment of sensor motes: 0, 90, 180, and 270.

TABLE IV

BATTERY CONSUMPTION

Voltage Level	Packet Size 10 Bytes		Packet Size 100 Bytes	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Initial	2.84 V	2.81 V	2.80 V	2.87 V
Residual	2.81 V	2.77 V	2.70 V	2.80 V
Consumed	0.03 V	0.04 V	0.04 V	0.07 V

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