Studying the Spatial Correlation of Loss Patterns Among Communicating Wireless Sensor Nodes

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BY

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Abstract—Simulation can be an important step in the development of software for wireless sensor networks and has been the subject of intense research in the past decade. The simulation software should account for all possible factors affecting the wireless sensor networks. In this study we have addressed the question of correlated loss in among the communicating wireless sensor nodes. The results might help us update simulation software. Our approach is to check the fluctuations in the reception rates of the sensor nodes by introducing physical interferences between sender and receiver nodes. We performed two series of experiments in different surroundings. We show how the introduction of the *line-of-sight* physical interference between sender and receiver affects the reception rates. The results from this study can shed new light over the question of correlated loss among sensor nodes, experiencing the same kind of physical interference.

I. INTRODUCTION

A. BACKGROUND

In the wireless world, there are many factors which would influence the effectiveness of the communication between the wireless nodes. In sensor networks, the traditional constraints of the wireless domain are coupled with the limitation of resources of the nodes themselves. Thus it is important to exactly know the reasons and patterns observed in the inter-node communication, to come up with better designed protocols and mechanisms to allow the sensor nodes to communication effectively and efficiently. Also the fact that most of the times researchers use simulations for research questions; it is important to know about all the factors affecting the performance in communicating nodes to answer questions about performance.

B. PROBLEM

The question addressed in this study is whether there the phenomenon of correlated loss among the wireless sensor nodes exists or not. For this purpose, a series of experiments was conceived. The aim of the experiments was to study the effect of physical interference on the reception rates of the sensor nodes. We first analyze the reception rates of the sensor nodes in a certain environment without any *line-of-sight* physical interference between sender node and the receiver nodes. The experiment is conducted again with the line-of-sight physical interference between sender and subset of receiver nodes. This comparison gives us a clear picture of what effect does the physical interference had on the nodes it was obstructing. Statistical methods are used to test the validity of the results.

II. EXPERIMENTAL DETAILS & METHODOLOGY

We conducted our experiments in two different environments. A series of experiments was conducted in the ILENSE lab at ISI. Due to the dimensions of the room, we could do the experiment with only 4 receiver nodes. The second series make up the core of the experiments, conducted for this study. These experiments were conducted in the conference hall. A total of 9 receivers were setup to receive broadcast packets from a single sender. Experiments are discussed in detail in the section III. The general methodology for the experiments remained identical for all the experiments. We will discuss some of the important aspects here.

A. ENVIRONMENT

The two series of experiments were conducted in two different rooms. We will list the important details about the environment of the rooms.

i) ILENSE LAB ROOM

The ILENSE lab has lots of furniture, computers and electronic stuff. It is a rectangular shaped long room. Among all the other types of furniture we have a big metal closet, four desktop computers completely covering the two ends of the room. The other furniture includes chairs, cupboard and tables. Not much space is left in the middle, but we were able to get the experiments done, with four receivers placed at equal distances from the sender.

ii) CONFERENCE HALL

The conference hall had to be the venue for our core experiments. It is a big room with chairs and tables being the only notable physical *interferences*. Due to large space we were able to include more receiver nodes in the experiments.

All experiments were conducted late at night. Although it was not intentional, but it did allowed to run the experiments in a quite atmosphere with minimum physical interference introduced by the people moving around.

B. PHYSICAL INTERFERENCES

The most important aspect of these experiments was the kind of physical interferences introduced. In the experiments conducted in the ILENSE lab, the *line-of-sight* physical interference introduced was the pair of aluminum cookie sheets. However, there was *non line-of-sight* physical interference present in the form of the metal closet, computers and the other furniture. These *non line-of-sight* physical interferences made up the surrounding environment for the experiments conducted in the ILENSE lab.

In the conference hall, other than the chairs and tables, which made up the standard environment of the hall, we introduced two steel sheets and a couple of aluminum cookie sheets as the main source of physical interference. One of the steel sheets was a single piece of solid steel with dimensions of about 4x3 inches and 0.2 inches thick. The other big steel sheet was made up from 3 pieces of steel cut from a steel roll. This steel sheet was around 4x6 inches with 0.2 inches of thickness. Standard Aluminum cookie sheets were also used.

C. TRAFFIC MODEL

The most important fact about the experiments conducted is the account of the traffic model used. We used a simple model for the traffic sent by the sender. The duration of each experiment was one hour. Although the data collected in this one hour was divided in to 10 non overlapping sets, which allowed us to look at the one hour experiment as 10 experiments of interval 6 min each. The data sent from the sender was a simple 'ping' packet. The size of a ping packet sent is 68 bytes. One packet was sent out in a second. So this makes the total packets sent out in an hour long experiment as 3600. For one interval of 6 min a total of 360 packets were sent out. The fixed interval between the packets sent out makes the distribution of the transmissions as normal.

D. *CODE MODIFICATIONS*

The applications running on the sender and receivers were 'ping' and 'pingd'. Ping application is a simple sender side application sending out the ping packets with a certain interval. The only modifications done to the code was to change the inter-transmission time for each packet, and to log the details of each packet sent out, in a file named after the ID of the sender node. Thus, a sender node with ID 76 will have a log file ilense76.out with format as:-

SENT TIME	TRANSMISSION POWER	PACKET ID
11292839192	1	76
11292839194	1	77
11292839196	1	78

The transmission power is not the dBm value. In fact it is the hexadecimal value which is used to setup the required power. The conversion can be done easily though tables given in [1].

The receivers on the other hand were running 'pingd' application. 'Pingd' is a passive application which receives, and logs the information from a received packet. The important information logged by our custom 'pingd' application was the Received Signal Strength Indicator (RSSI) and the received packet ID. The log file names are in similar pattern as the sender and would have a typical format as:-

RECIEVED TIME	RSSI	PACKET ID
11292839192	164	76
11292839194	149	77
11292839196	157	78

The RSSI here is the value reported to us by the underlying code though link level packet. This is not the actual dBm value. This is in fact the ADC_Counts value which is converted to dBm values through the formulas given below.

$$Vrssi = Vbatt * ADC\_Counts/1024$$
$$RSSI = -51.3 * Vrssi - 49.2.$$

Vbatt for the radios is 3V.

MAC PROTOCOL
The MAC protocol used in the sensor nodes was B-MAC.

E. PHYSICAL ARRANGEMENT OF NODES

The nodes are physically arranged by keeping in mind two factors: distance and the angular position with respect to the sender.

Distance is one of the major factors affecting communication among wireless devices. We tried to keep the distance equal among the receiving nodes. Although one of the flaws in the experiments conducted in the conference hall was the unequal distances of the receiver nodes in a quarter-circle, but we can still say that at least 2 nodes were at the same distance from the sender in the experiments. Thus we can say that actually there were subset of receiving nodes that were at equal distance from sender as one set. This limitation had to be introduced due to the dimensions of the room, and the *effective range* concept of the propagating radio waves. Although, one measure that can be taken to avoid such discrepancy is to conduct half-circle experiments rather than full-circle experiments.

The receiver nodes were arranged in a circular fashion, in that they were placed at a certain degree angle from the sender. Thus the nodes in the experiments in the ILENSE lab were placed at 30,150,210,330 degrees and the nodes in the conference hall were placed at 30 degrees difference in a circular fashion around the sender.

F. STATISTICAL METHODS

The raw data that we got from the experiments in the log files was processed statistically to get the information about means, confidence intervals, variances and reception percentages. We used the scripts from [14] to generate the means and confidence intervals. The data was collected from each receiver node over the experiment time, in one file. The logs recorded the Time, RSSI, and Packet ID of each of the packets received by the node. To calculate means and confidence intervals from the data collected; the log file was divided into 10 files. Each file includes the record of 6 min interval.

To calculate means and the confidence intervals first each of the 10 logs of each of the four receiver nodes were processed with the 'dbstats' utility [14]. The results were stored in different files; one each for each receiver. The column processed by dbstats was the RSSI. The number of instances counted in the file would give the number of packets received and thus the reception percentage in each interval of 6min. Specific data i.e. Mean of RSSI and Reception percentage in each interval is collected in another file. The utility of dbstats is again used to computer the final Mean RSSI, its low and high confidence level values and Mean Reception percentage and its low and high confidence level values. To verify that the means with interference are statistically different from the means without interference, we employed the concept of hypothesis testing. In this method we see whether the means after introducing the interference fall outside the confidence intervals of the means without interference. If they do, then we say that this change in the means is significant enough to be caused by the interference. Our graphs discussed in the section IV are analyzed based on this concept.

G. GRAPHS & SCRIPTS

The Gnuplot utility for Windows XP is used to plot the graphs. Some scripts in Perl Language were used to manipulate the data in the log files.

III. EXPERIMENTS

A. EXPERIMENTS IN ILENSE LAB

Two Experiments were conducted in the ILENSE lab. First experiment was conducted without any *line-of-sight* interference and the second one did include *line-of-sight* interference in the form of aluminum cookie sheets.

i) Experiment Without Line-of-sight Interference

TOPIC

The aim of this first experiment was to find out the loss rates, and possible spatial correlation in loss patterns, without the line of sight interference. Thus this experiment will give us the base results in the environment of the lab to which the results of the second experiment would be compared.

WHY IMPORTANT

This experiment is important to understand the communication patterns among the communicating wireless sensor nodes. This experiment provided a bench mark for the other experiments as it provides the primary data about the reception rates among receiver nodes which are not obstructed from the sender by any physical interference.

HYPOTHESIS

My hypothesis for this experiment was that we will experience essentially similar loss rates with stable means. This hypothesis is based on the fact that the shortest path for the radio waves from the sender to receivers, which is a straight line, was not obstructed by any kind of interference.

METHODOLOGY

A total of 5 nodes took part in this experiment. One of them was designated as sender node and 4 others received packets from it. The receiver nodes were placed at equal distance from the sender and the degree measure of the nodes was 30,150,210 and 330. No Physical interference was introduced in the line-of-sight. The logging of the data was done according to the format given in section II.

EXPECTED RESULTS

I expected the reception rates to be nearly equal for all the receiver nodes. I also expected the means to be stable with less variation.

PARAMETERS

Number of Nodes:-   5
Sender(s) Nodes:-   1
Receiver(s) Nodes:-   4
MAC Protocol:-   BMAC.
Time:-   60 minutes.

PHYSCIAL PLACEMENT OF THE NODES.

The physical placement of the nodes is shown in the Figure 1.1. The actual setup of the nodes in the lab room is also shown in the figures 1.2 & 1.3. The sender is shown in blue, while the receivers are shown in red circles.
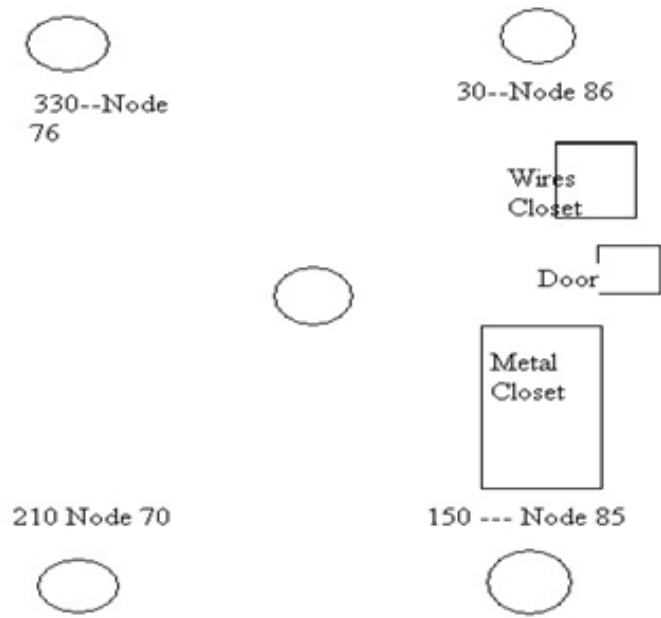
330--Node 76

30--Node 86

Wires Closet

Door

Metal Closet

210 Node 70

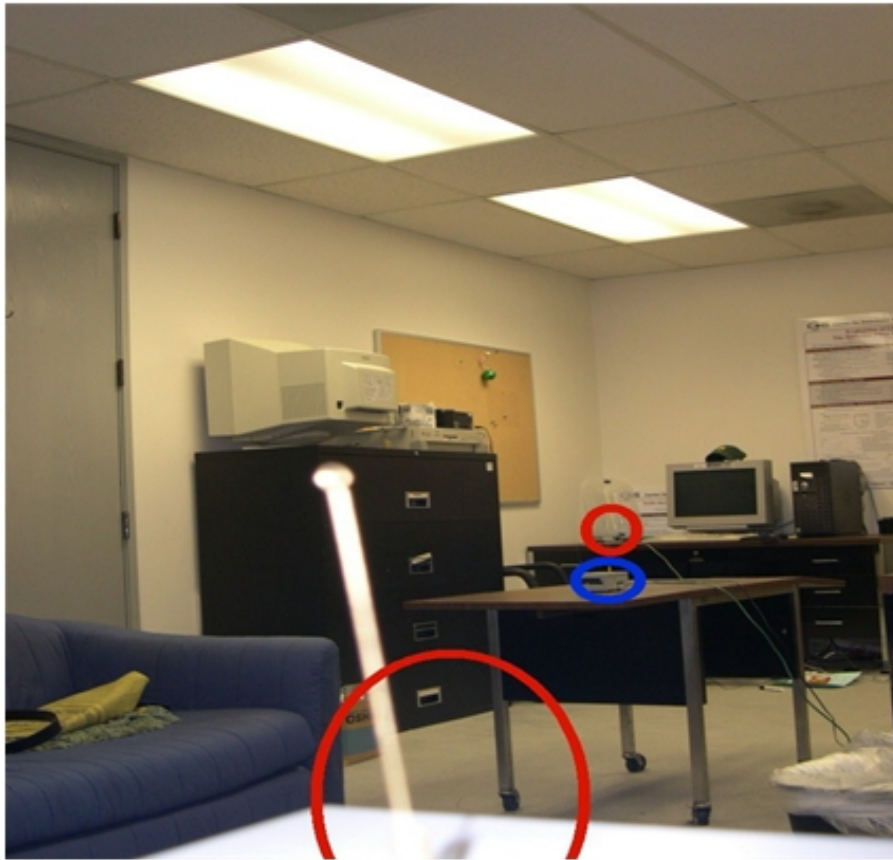150 --- Node 85

Figure 1.1

Figure 1.2

Figure 1.3

OBSERVED RESULTS

The results from the experiment were largely confirming the hypothesis. Only one node which was right beside the closet did experience extra-ordinary loss and large variation. However, we cannot blame the closet for this behavior for sure, because we conducted the experiment for the same node again by changing its position slightly and its reception improved tremendously. We know from related research that even a slight change in the position of the wireless nodes is enough to change its reception behavior significantly. We now analyze the results we got through the graph. Graph in Figure 1.4 shows the original experiment with one node showing huge variations and unstable mean. The graph in Figure 1.5 shows the node being moved and with better reception rates.
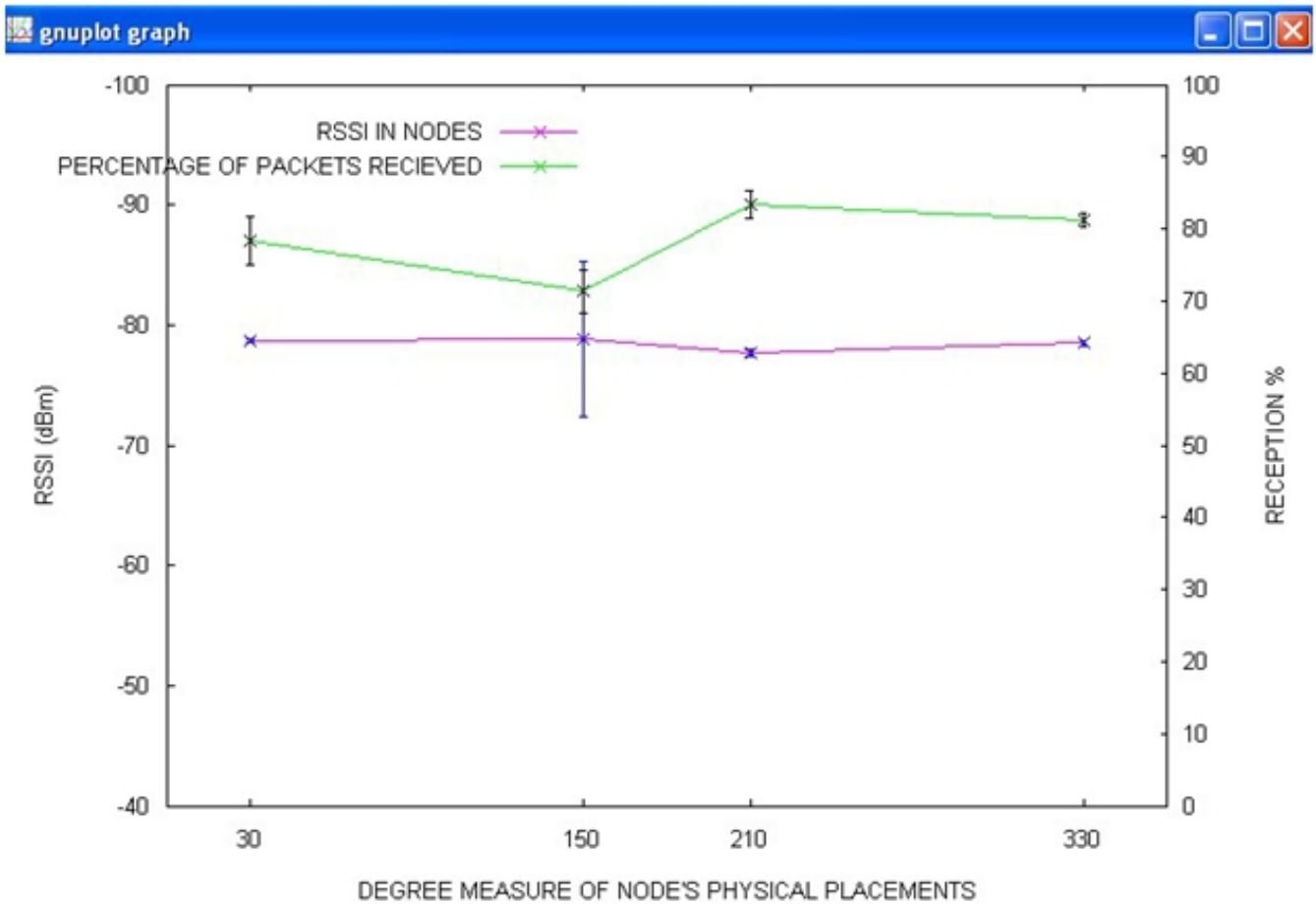
Figure 1.4

Gnuplot is used to plot the graphs of the data. We can see the reception rates and RSSI measured at each node. The node at 150 degrees shows high variation in RSSI and a huge difference in the reception percentage compared to the other nodes. All the other nodes have stable means for the RSSI and less variations in the reception percentage. We now take a look at the results form the experiment with changed position of the node at 150 degrees. It is shown in the figure 1.5.
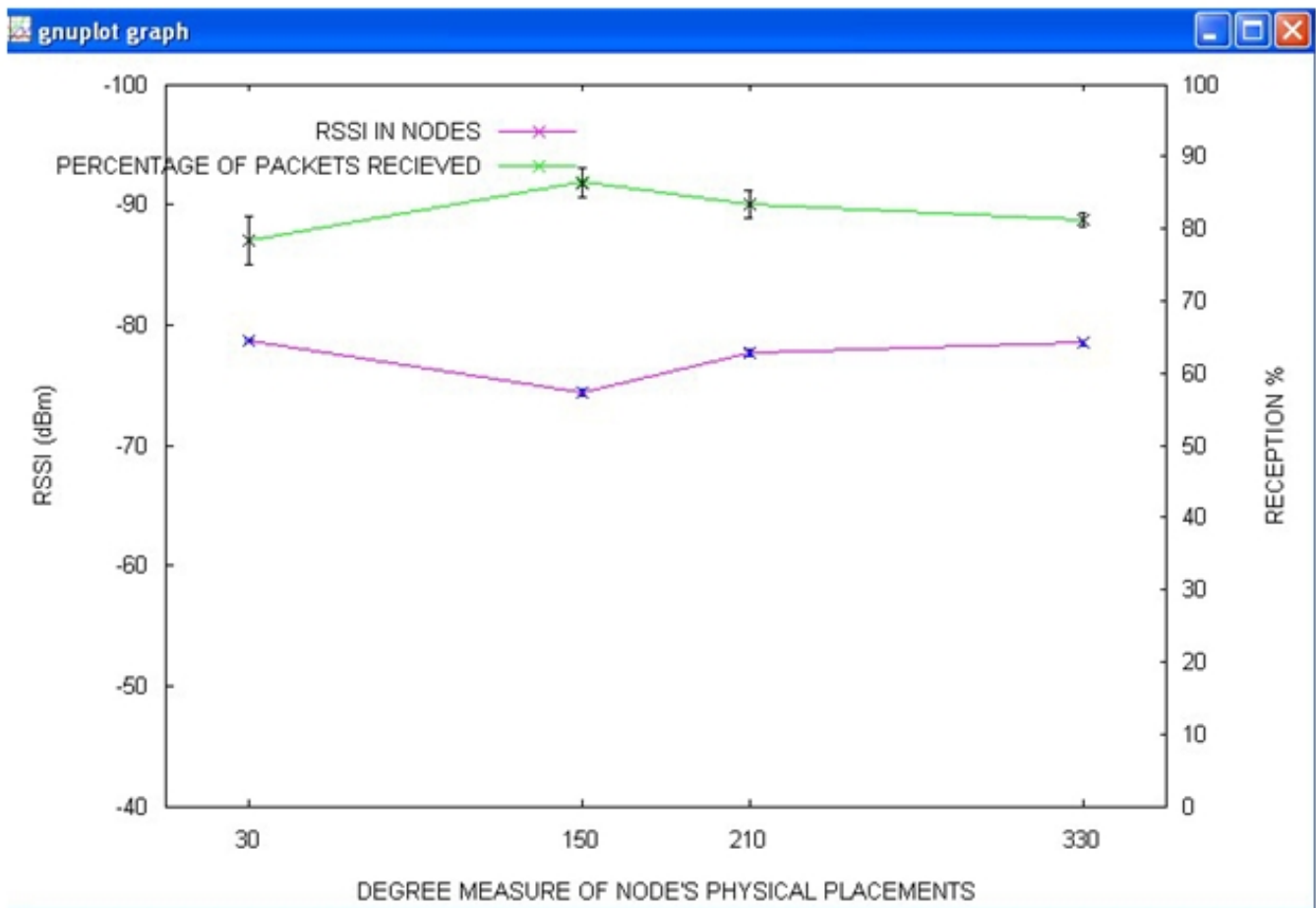
Figure 1.5

ANALYSIS

Figure 1.4 shows the graph of achieved after the variance analysis of the first experiment. We can see that the Reception percentages are generally calculated to be around the 80% mark. The RSSI is between the -75 to 80dBm level. The numbers showing RSSI are the mean of the actual values that a node records from a packet received. There is huge variation of received power for the node at 150 degrees (ilense85). We can see in Figure1.2 that there is a huge metal closet very near to that node. But we cannot say for sure that it was the source of this variation in RSSI at 150. This point will be discussed later in analysis of other graphs.

The expectation before this experiment was to see generally the same mean RSSI and reception percentages among the nodes as there is no line of sight physical interference. So, for the most part, the results of the experiment endorse that hypothesis. The ILENSE lab has a lot of potential physical interferences which although are not in line of sight, but are there. We see that the reception percentage in three of the nodes was just about same. By changing the position of the node at 150 degrees (thinking that the metal closet was causing the interference) from 150 to around 175 degrees mark. We see that changing the position of the node changed the reception behavior of the wireless sensor node. The RSSI is much more stable and better, and the reception percentage is also better than all the other nodes. So essentially we can say our hypothesis is endorsed as most of the nodes appeared to get the results as expected. But we must acknowledge the variations caused by the surroundings.

ii) *Experiment with Line-Of-Sight Interference.*

TOPIC

The aim of this experiment was to find out the loss rates, and possible spatial correlation in loss patterns, with the line of sight interference.

WHY IMPORTANT

This experiment is important as it would give us the information about the changes in the reception rates and changes in the RSSI when line-of-sight interference was introduced.

HYPOTHESIS

My hypothesis for this experiment was that we will experience increase in the loss rates for the subset of nodes which are behind the physical interference. We should also see drop in the RSSI for these nodes.

METHODOLOGY

Same setup was used as in the previous experiment. The only difference was the aluminum cookie sheets which were introduced as the line-of-sight physical interference between sender and the receiver nodes at 30 and 330 degree.

EXPECTED RESULTS

I expected that we will experience increase in the loss rates for the subset of nodes which are behind the physical interference. We should also see drop in the RSSI for these nodes.

PARAMETERS

Number of Nodes:-   5
Sender(s) Nodes:-   1
Receiver(s) Nodes:-   4
MAC Protocol:-   BMAC.
Time:-   60 minutes.

PHYSCIAL PLACEMENT OF THE NODES.

Physical placement of the nodes is the same as depicted in Figure 1.1, and Figure 1.6 shows the actual placement of the aluminum cookie sheets in the setup.
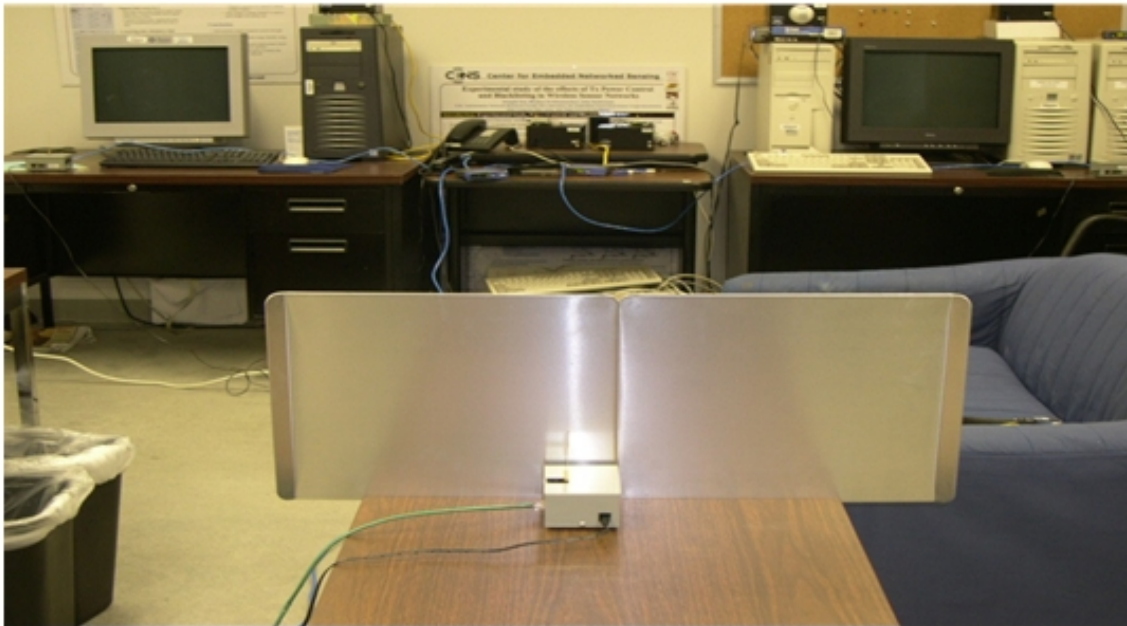
Figure 1.6

OBSERVED RESULTS

As we expected, the results showed less reception percentages for the nodes that were behind the physical interference. Although, the point to note was the amount of difference that the nodes behind the interference had in their reception percentages. We can also see the result with the help of a graph in Figure 1.7.
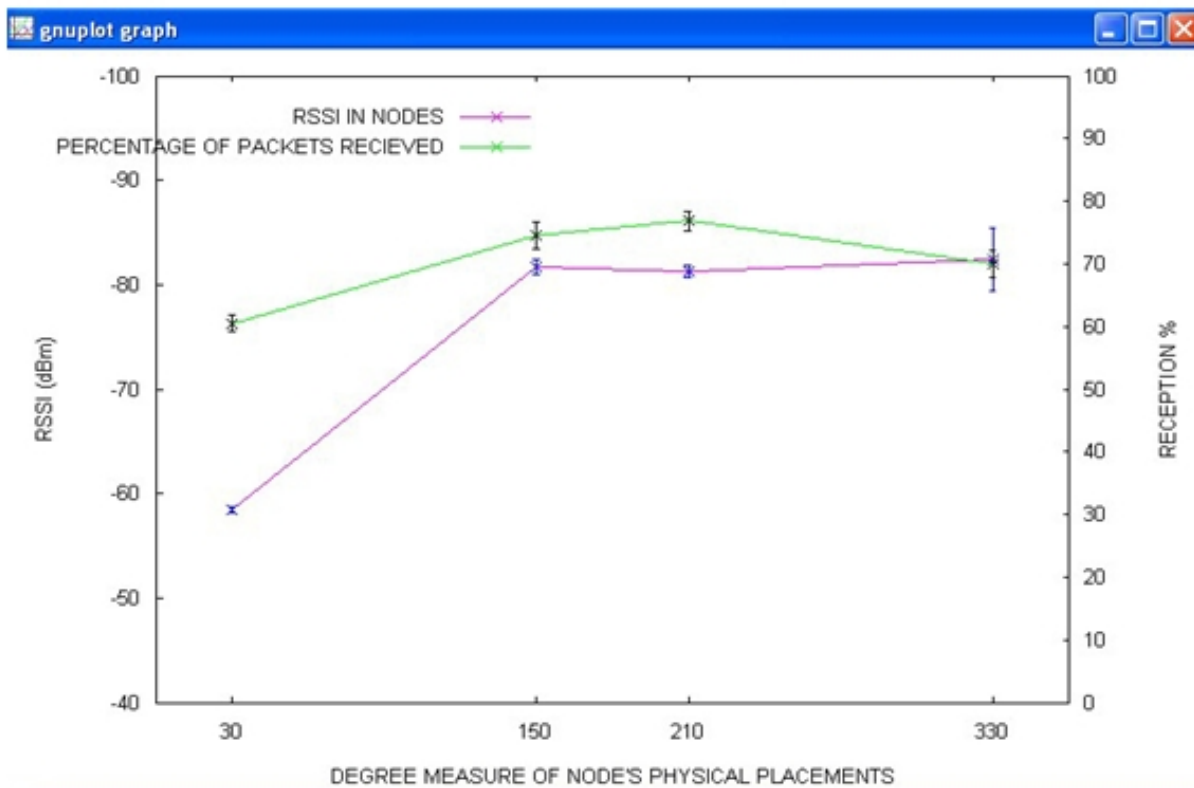

Figure 1.7

ANALYSIS

Figure 1.7 shows the experiment done with interference placed in line of sight between two receivers and the sender. These two receivers were ilense86 placed at 30 degrees, and ilense76 placed at 330 degrees. Aluminum cookie sheets were placed just in front of the sender to block line of sight between it and the receivers. The distance was around 6 inches.

If we go by numbers, the reception at the nodes obstructed comes out to be less than the nodes with no line of sight obstruction (by at least 5%). However, there is significant difference between the reception rates of the two nodes behind the interference (almost 10%). The node that got punished more was at 30 degrees. To our surprise, we see that a better RSSI for the node at 30 degrees doesn't translate in better reception rate. This is one shift from the general observation we can note from this result. But generally, we can say that the results of this experiment confirm our hypothesis of lower reception among nodes on one side of the sender where physical interference was introduced. Although we haven't seen a consistent increase in loss, but still it is there.

B. EXPERIMENTS IN CONFERENCE HALL

Core experiments were conducted in the conference hall. A total of three experiments were conducted. First experiment was conducted without any *line-of-sight* interference and the second and third included *line-of-sight* interference in the form of aluminum cookie sheets, and steel sheets. The difference between the second and third experiments was the distance of the physical interferences from the sender node.

i) Experiment Without Line-of-sight Interference

TOPIC

The aim of this first experiment was to find out the loss rates, and possible spatial correlation in loss patterns, without the line of sight interference. Thus this experiment will give us the base results in the environment of the lab to which the results of the second and third experiments would be compared.

WHY IMPORTANT

This experiment is important to understand the communication patterns among the communicating wireless sensor nodes. This experiment provided a bench mark for the other experiments as it provides the primary data about the reception rates among receiver nodes which are not obstructed from the sender by any physical interference.

HYPOTHESIS

Our hypothesis for this experiment was that we will experience essentially similar loss rates with stable means. This hypothesis is based on the fact that the shortest path for the radio waves from the sender to receivers, which is a straight line, was not obstructed by any kind of interference. We also have experienced the same behavior in the previous experiments.

METHODOLOGY

A total of 10 nodes took part in this experiment. One of them was designated as sender node and 9 others received packets from it. The receiver nodes were divided in subset and nodes within a subset are placed at equal distance from the sender and the receivers were placed at 30 degrees difference from each other. No Physical interference was introduced in the line-of-sight. The logging of the data was done according to the format given in section II.

EXPECTED RESULTS

        I expected the reception rates to be nearly equal for all the receiver nodes. I also expected the means to be stable with less variation.

PARAMETERS

Number of Nodes:-	10
Sender(s) Nodes:-	1
Receiver(s) Nodes:-	9
MAC Protocol:-	BMAC.
Time:-	60 minutes.

PHYSCIAL PLACEMENT OF THE NODES.

The physical placement of the nodes is shown in the Figure 1.8. The actual setup of the nodes in the hall is also shown in the figures 1.9 & 2.0. The sender lies in the center, while the receivers are placed around it in a near circular fashion. Nodes from 60 to 120 degrees, shown in black box, didn't work.
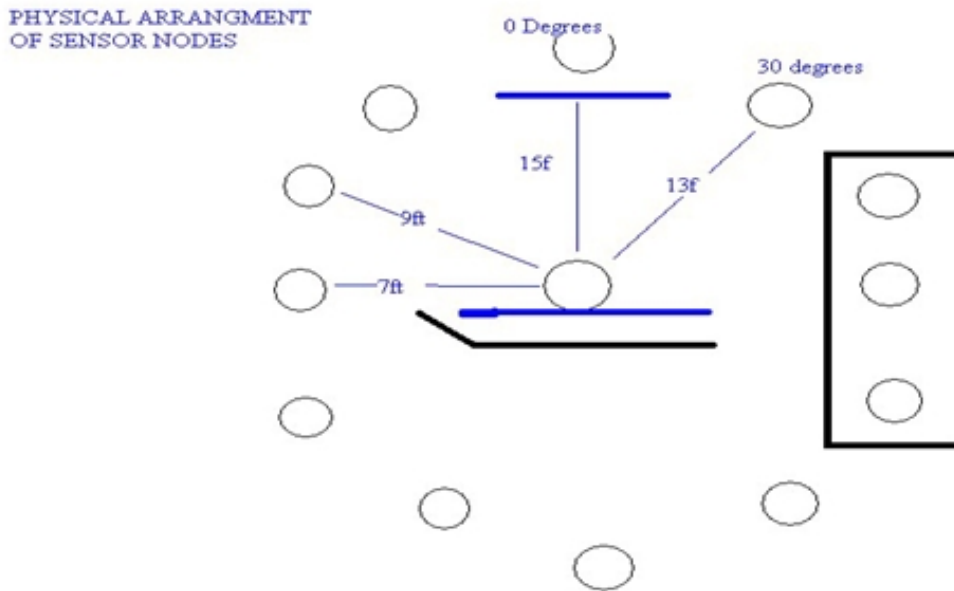

Figure 1.8

Figure 1.9

Figure 2.0

OBSERVED RESULTS

We can observe the results of RSSI and reception percentages in the figure 2.1. The graph shows that the reception percentage generally varied between 70 and 80% mark. One node at 180 degrees had exceptional reception rate at around 85% although it belongs to the subset of nodes which were at 15m distance from the sender. But to counter any false conclusions from this, the node right opposite to it, at 15m too received less than 70 % of packets and was one of the two nodes receiving much less than other nodes. A node that worked erratically throughout this experiment was at 330 degrees. It received around 15% of the packets but it must be a temporary flaw, as the same node received much more from the same position in the next experiments which we will discuss later. So this graph gives us the benchmark results to compare with the results from the experiments with interference. One important thing to note here was the variation in reception rates experienced by most of the nodes. We see that except one node, all others have experienced stable mean values for RSSI and Reception rates. There wasn't much variation on display. We will use these results to compare and draw some conclusions at the end of our discussion of experiments.
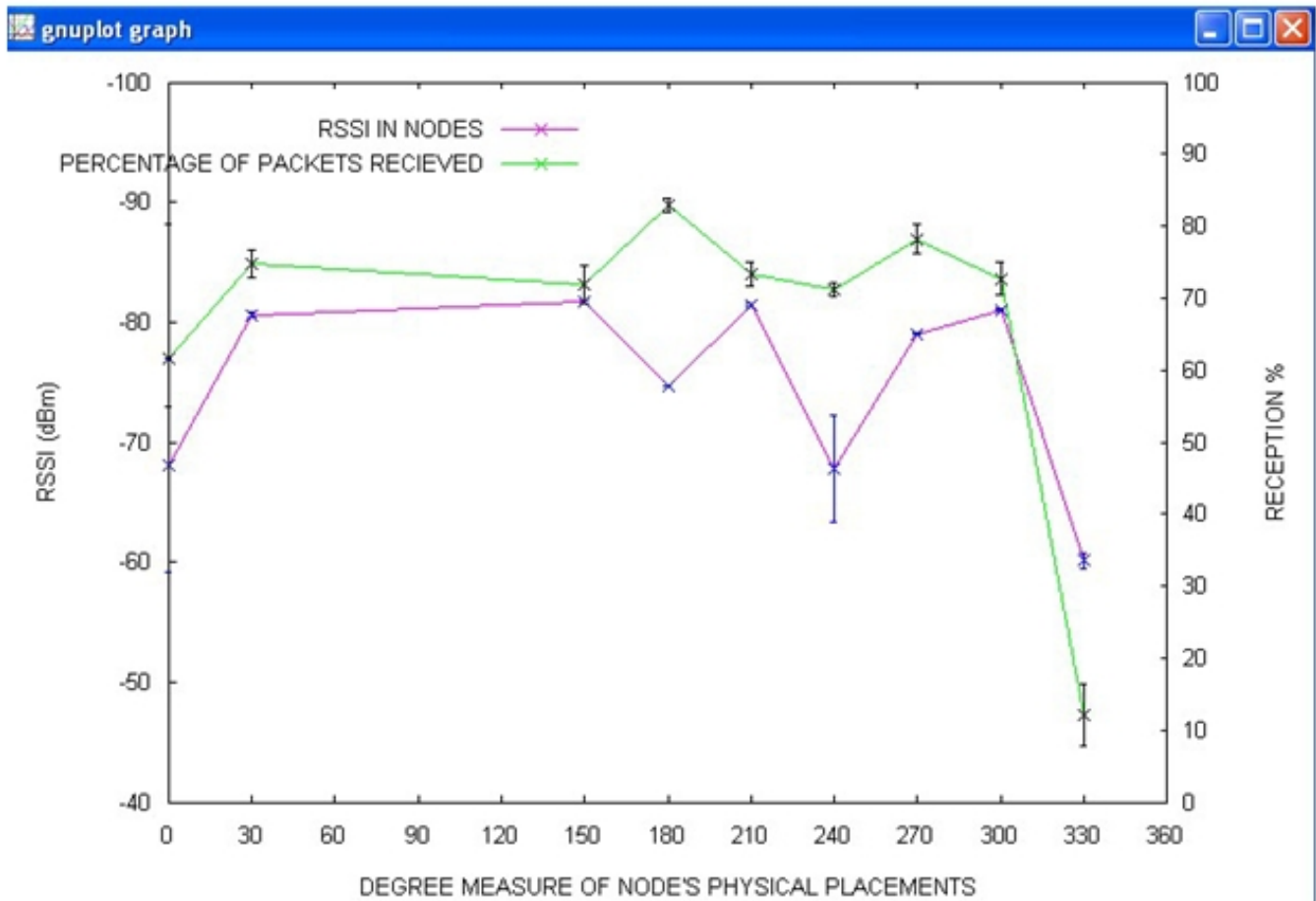

Figure 2.1

ii) Experiment with Line-of-sight Interference

TOPIC

The aim of this experiment was to find out the loss rates, and possible spatial correlation in loss

patterns, with the line of sight interference.

WHY IMPORTANT

This experiment is important as it would give us the information about the changes in the reception rates and changes in the RSSI when line-of-sight interference was introduced.

HYPOTHESIS

My hypothesis for this experiment was that we will experience increase in the loss rates for the subset of nodes which are behind the physical interference. We should also see drop in the RSSI for these nodes.

METHODOLOGY

Same setup was used as in the previous experiment. The only differences were the aluminum cookie sheets and two steel sheets which were introduced as the line-of-sight physical interference between sender and the receiver nodes at 150,180 and 210 degree.

EXPECTED RESULTS

I expected that we will experience increase in the loss rates for the subset of nodes which are behind the physical interference. We should also see drop in the RSSI for these nodes. (*The drop in the RSSI dBm values will take the point higher on the plot because all are negative values*)

PARAMETERS

Number of Nodes:-   10
Sender(s) Nodes:-   1
Receiver(s) Nodes:-   9
MAC Protocol:-   BMAC.
Time:-   60 minutes.

PHYSCIAL PLACEMENT OF THE NODES.

The physical arrangement is the same as shown in figure 1.8. We show in Figures 2.2, 2.3 the actual setup of the physical interferences.

Figure 2.2

Figure 2.3

OBSERVED RESULTS

We can observe the results of RSSI and reception percentages in the figure 2.4. The graph shows that the reception percentage generally varied between 70 and 85% mark. The nodes behind the interference were at 150,180 and 210 degrees. We see that all of them received around 69% of the reception but we will show in the third experiment that it is not a consistent observation that all nodes behind interference may receive very close percentages. One important observation in the graph is the amount of variation that is experienced by the nodes in their reception rates. The variation is significant and is experienced by most of the nodes, irrespective of their position i.e. Obstructed by interference or not. We will show the comparison of the graphs of these three experiments after we discuss the experiments separately first.
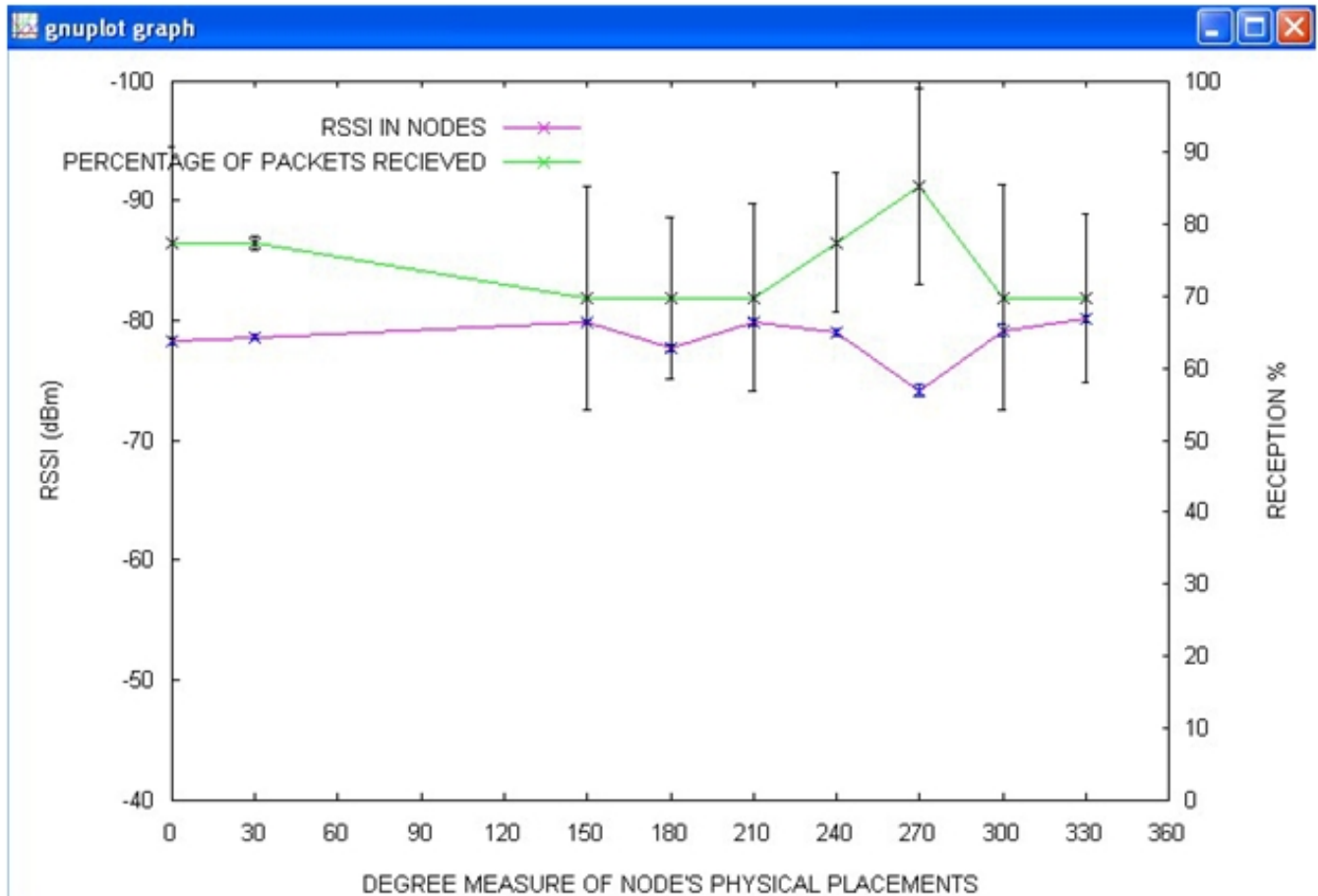

Figure 2.4

iii) Experiment with Line-of-sight Interference closer to sender node

TOPIC

The aim of this experiment was to find out the loss rates, and possible spatial correlation in loss patterns, with the line of sight interference which is very close to the sender node.

WHY IMPORTANT

This experiment is important as it would give us the information about the changes in the reception rates and changes in the RSSI when the position of the line-of-sight interference was

changed.

HYPOTHESIS

My hypothesis for this experiment was that we will experience more increased loss rate than the last experiment where we had interference some distance away from the sender node.

METHODOLOGY

Same setup was used as in the previous experiment. The only difference was the position of the line-of-sight physical interference between sender and the receiver nodes at 150,180 and 210 degree. The interference was now less than a foot away from the sender node. Also we have introduced aluminum interference, very close to one of the receiver nodes, which is at 0 degrees.

EXPECTED RESULTS

I expected that we will experience increase in the loss rates for the subset of nodes which are behind the physical interference. We should also see drop in the RSSI for these nodes. (*The drop in the RSSI dBm values will take the point higher on the plot because all are negative values*)

PARAMETERS

Number of Nodes:-   10
Sender(s) Nodes:-   1
Receiver(s) Nodes:-   9
MAC Protocol:-   BMAC.
Time:-   60 minutes.

PHYSCIAL PLACEMENT OF THE NODES.

The physical arrangement is the same as shown in figure 1.8. We show in Figures 2.5, 2.6 the actual setup of the physical interferences.

Figure 2.5

Figure 2.6

OBSERVED RESULTS

Contrary to what as expected the reception in the nodes which were obstructed by the interference improved from the last experiment. Although it still remains lower than the first experiment without interference. Another important thing to note is the change in the reception rates of these nodes, which was quiet uniform among these receiver nodes, but is now different. Another important observation is the lack of large confidence intervals in the reception rates of the nodes in general. However the nodes which are behind the steel sheet interference still have relatively large confidence intervals. The node at 0 degrees which is shown obstructed by aluminum sheets in figure 2.6 shows not much change in the reception rates compared to the previous experiment.
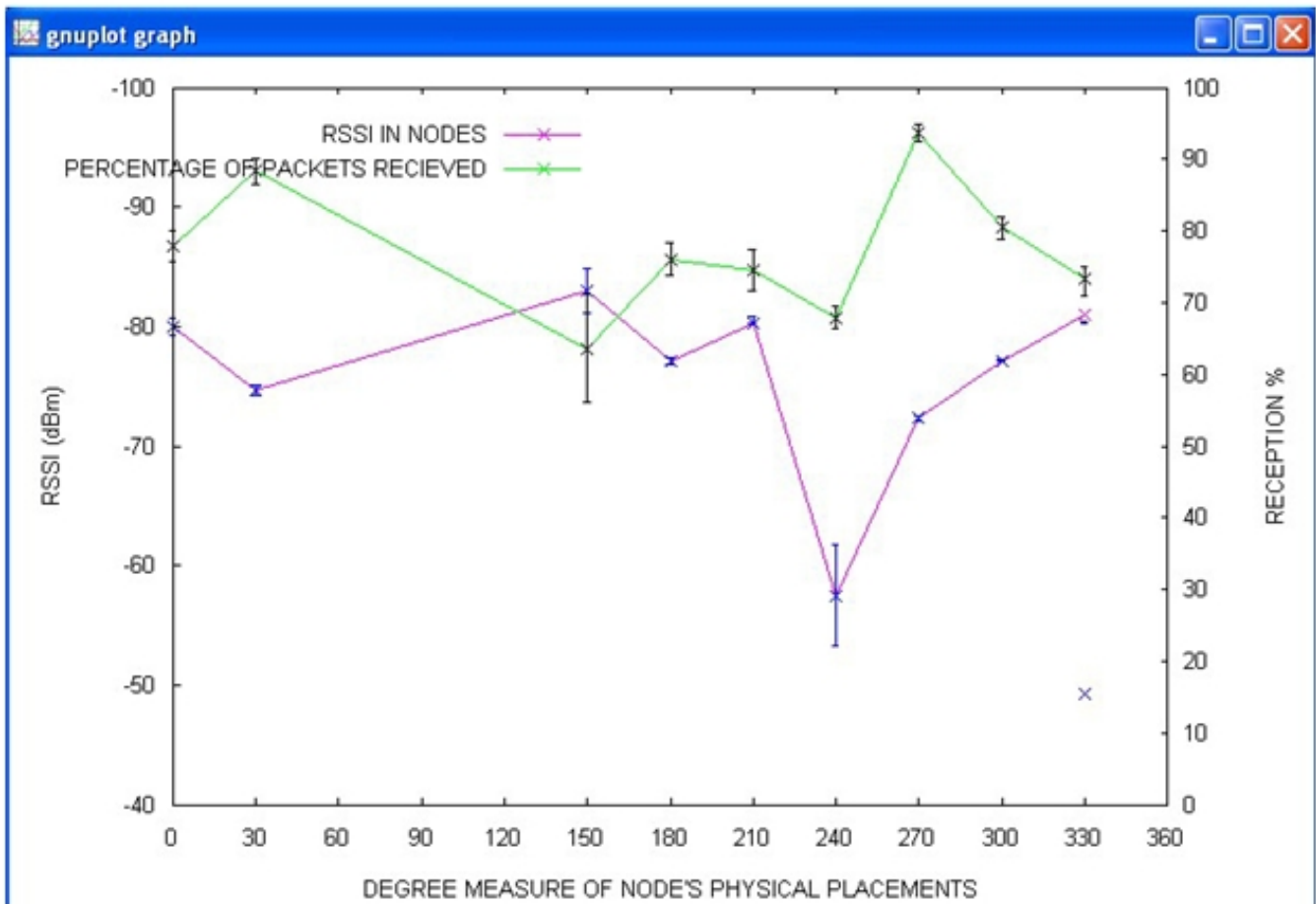
Figure 2.7

IV.COMPARISON OF THE RESULTS FROM THE EXPERIMENTS

A. Experiments in the ILENSE Lab.

We first compare and analyze the results we got from the ILENSE lab experiments. We show 2 different graphs in Figures 2.8 & 2.9.
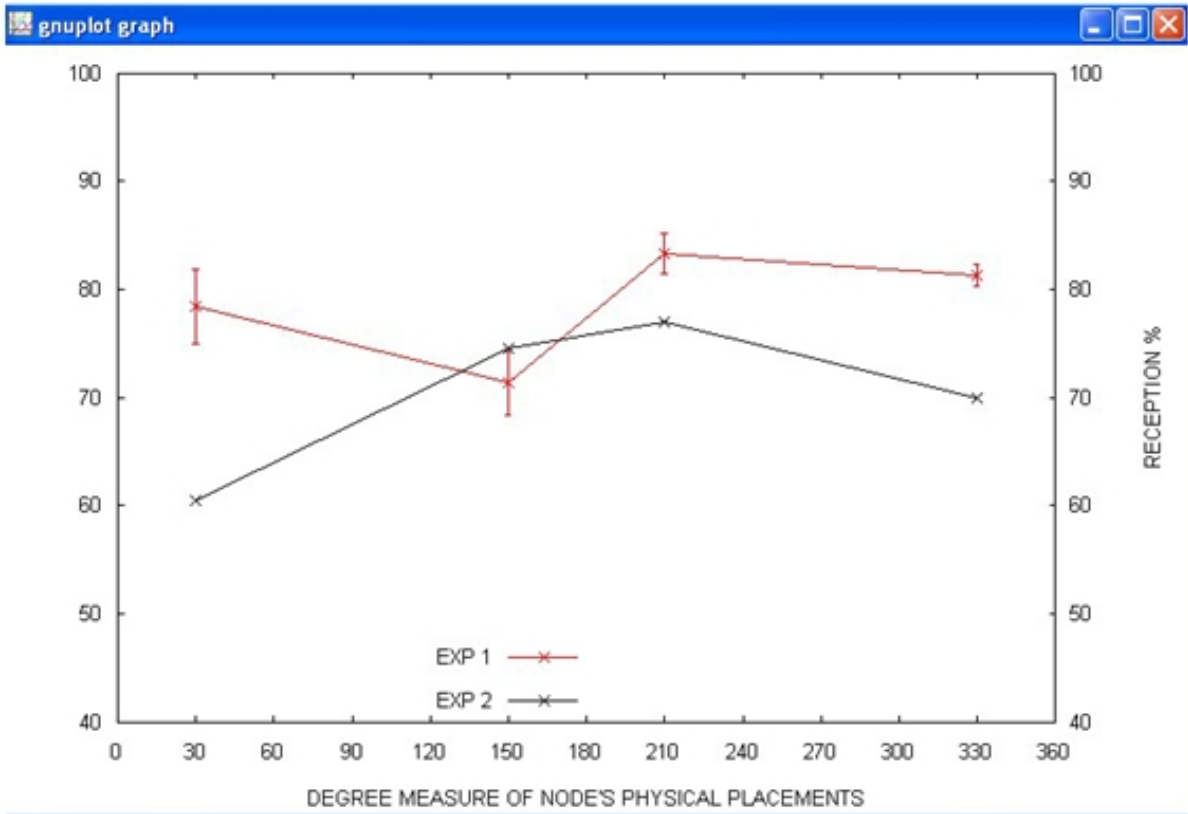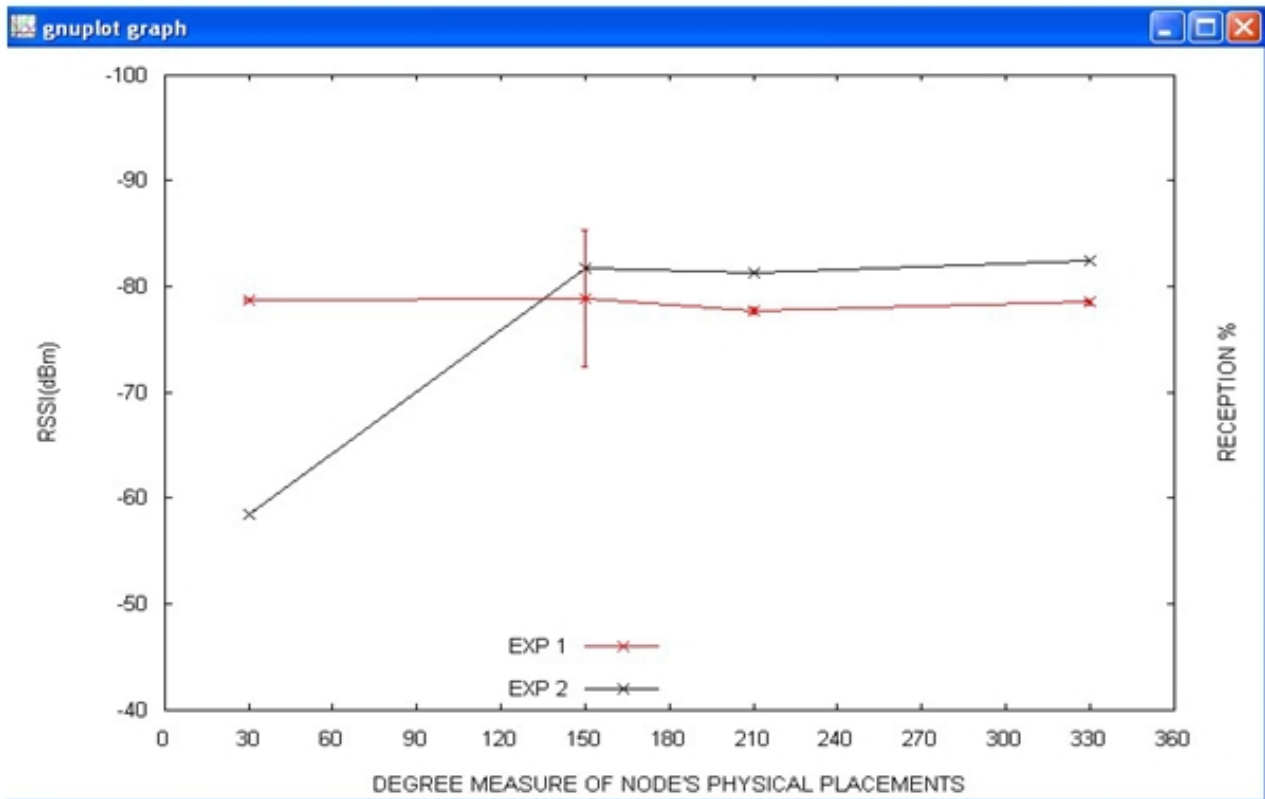
Figure 2.8

Figure 2.9

DISCUSSION

We have presented the graphs which compare the results from the two experiments in the ILENSE Lab. We observe in the Figure 2.8 that the mean percentage dropped for all the nodes. But it is visible that the two nodes which were behind the interference in the second experiment (nodes at 30, 330 degrees) experienced loss values which were far less than the confidence interval of the first experiment. Although one of the unobstructed node also experienced fall outside the confidence interval of the mean in the first experiment, but the other node experienced no such change. So we can safely say that due to interference, in this experiment, there was a significant fall in the reception rates. The graph in figure 2.9 shows the changes in the RSSI values. We see that generally the RSSI values dropped, but for one node at 30 degrees. This node experienced huge loss, but the signal strength it got was very good. This result is confusing as it dents our general observation that the better signal strength results in better reception rates. We take these results and now compare the results from the experiments in conference hall.

B. Experiments in the Conference Hall

We will present a number of graphs here and discuss the observations made in the experiments in the conference hall.
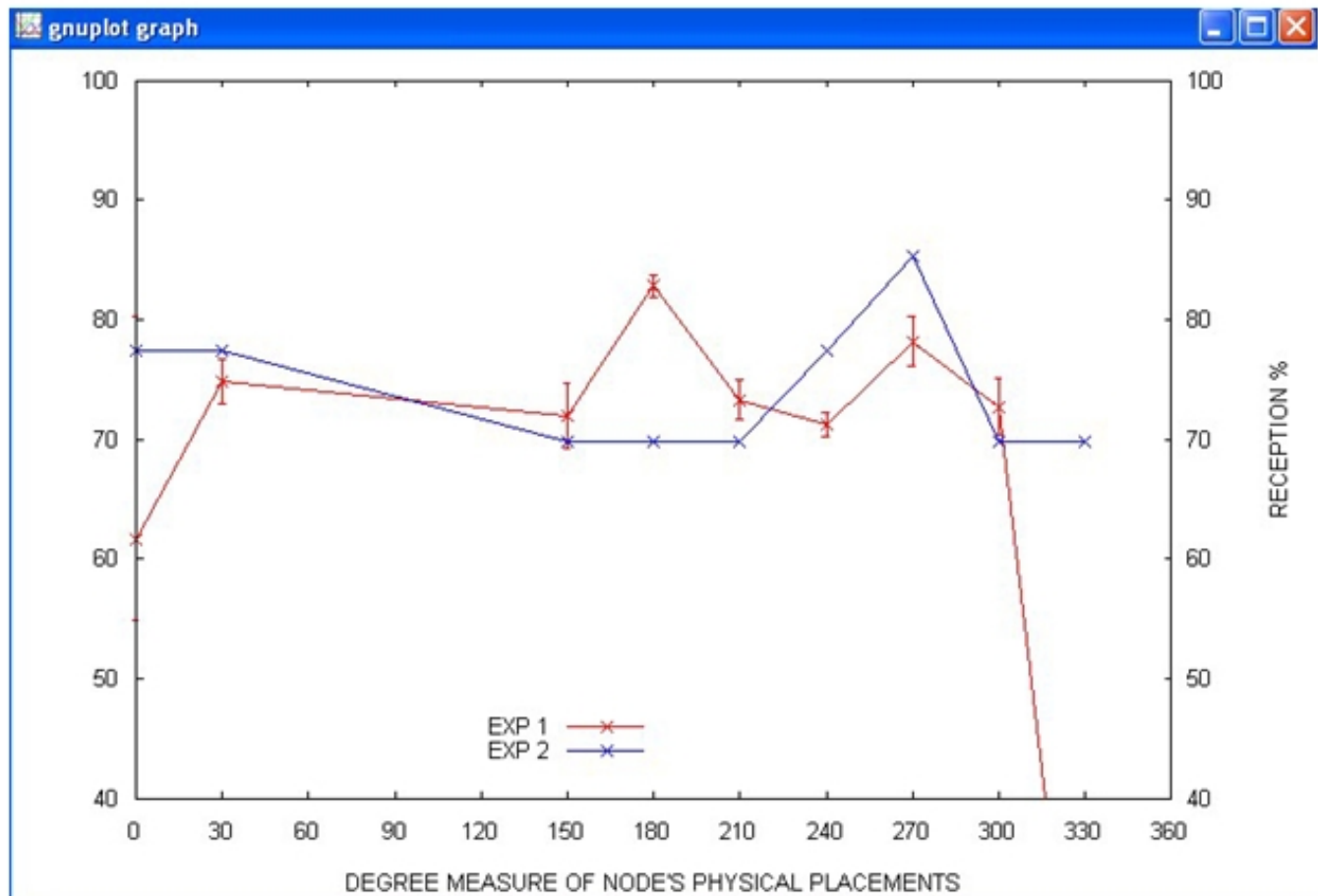

Figure 2.10

The graph in figure 2.10 shows the reception percentage with confidence intervals from experiment 1 and also the reception percentages 'without' confidence intervals from the experiment 2 where interference was introduced. The importance of this graph is that it shows if changes in mean percentages observed in exp 2 compared to exp 1 are genuinely because of the interference or not. In other words this graph encapsulates in itself the result from the hypothesis testing theory discussed in the statistical methods, in section II. As we have shown with the 95% confidence intervals from the first experiment, we can observe substantial changes in the reception percentage values from the three nodes behind the interference. These three nodes are at 150,180,210 degrees. We see that nodes at 180 and at 210 have experienced reception rates values which fall outside the 95% confidence intervals in exp 1. In case of node 150, the value is just at the border of the interval so we cannot take it as a solid proof. But the values from the other two nodes tend to confirm our hypothesis that our means when calculated with and without interference are statistically different.

However, another observation that is a key here is that the introduction of interference had its effect on the nodes that were not directly obstructed by them. Most of the other means have also changed. By looking at the figure 2.4 we see that the 95% confidence intervals have widened a lot, and for every node. Now if we consider that, we cannot say outright that our hypothesis is endorsed.

Now let us take a look at the graph comparison from exp 1 and exp 3 where the interference is placed very close to the sender. The graph is shown in figure 2.11.
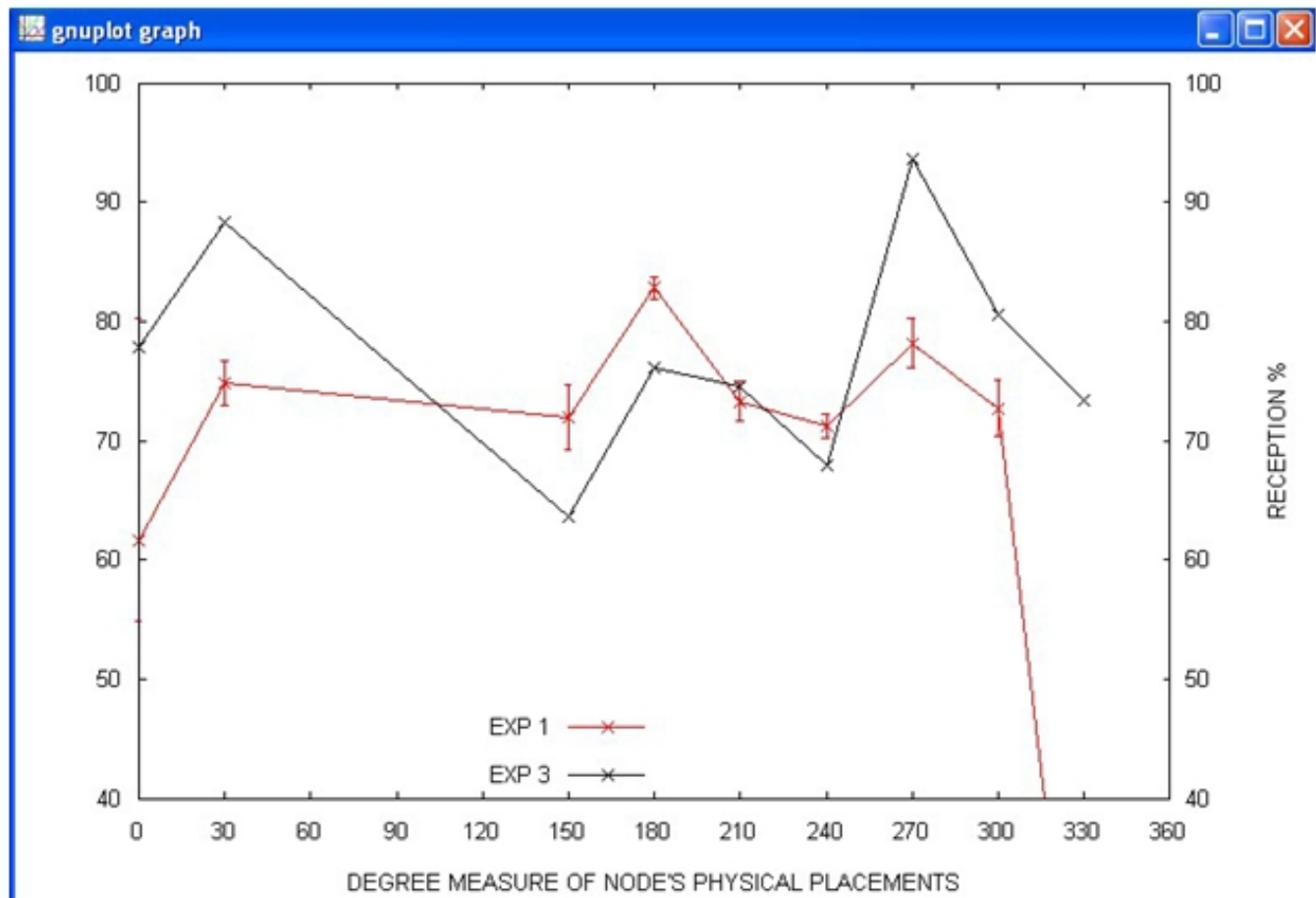

Figure 2.11

Luckily we have a set of results where the means are relatively stable. We can see the confidence intervals in exp 3 in the graph shown in Figure 2.7. In figure 2.11 we have shown a similar graph to

2.10 but it is between exp 1 and exp 3 data. Here we again see that for most of the nodes the mean values have changed significantly. For the nodes 150,180 & 210 we see that the values are generally outside the confidence interval from exp 1. Although, just like 2.10 we see that one of these nodes has the mean value just inside the confidence interval. That can be taken as a tentative value. In both the graphs, we see that the values just fall inside the intervals. Although statistically we would not base our results on them, but we also see in the same experiments two other obstructed nodes showing substantial difference in mean values i.e. outside the confidence intervals. In this experiment we also see the means are relatively stable compared to the values in exp2.

But one thing remains the same and that is the behavior of the mean values from the nodes that are not obstructed. They also show the significant difference outside the confidence intervals. Thus we would refrain from outright stating that interference had the only major effect on the mean reception rates in receiver nodes. What we can say with much more confidence though is the fact that the introduction of interference did change the variance in the mean reception rate values of all the nodes. The 95% confidence intervals in exp2 and exp3 are larger compared to the confidence intervals in exp1.

V. CONCLUSION

We have studied the effect of physical interference on the reception rates and RSSI to answer the question of spatially correlated loss among receivers being obstructed compared to those which are not. We have analyzed through the graphs and statistical methods the data collected in the experiments. Our hypothesis was that the calculated means reception rates of the receivers with and without physical interference are statistically different. We may not be able to make any outright statement on the basis of the proof we have, but we can certainly say that effects of the interference are visible. We can however make a few important observations here.

1) We got increase in the variance of the mean reception rate values once we introduced physical interference.
2) The introduction of physical interference not only affects the nodes obstructed in the line of sight but also the other nodes in the vicinity. The multi-path phenomenon might be a big reason for this behavior of the nodes.
3) Physical interference does effects the receptions of the nodes it obstructs, but the amount of loss cannot be predicted to be consistent among those nodes. The variation in the means is sufficiently large to prevent us from definitely relating these effects observed here to a verdict of essential correlated loss among receivers obstructed.

It may be helpful to conduct more experiments in different environments to learn more about the subject.

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