WIRELESS SENSOR NETWORK SCHEDULING AND COVERAGE USING AN ABC ALGORITHM

A Paper
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Software Engineering

January 2015

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Wireless Sensor Network Scheduling and Coverage Using an ABC Algorithm

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MASTER OF SCIENCE

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ABSTRACT

Limited sensor battery capacity is a major issue in wireless sensor networks. If all of the sensors in a network need not be in an awake state to provide adequate coverage at any given time, it is possible to strategically schedule their awake and sleep times to extend useful network lifetime.

In this paper we present two heuristic methods for sensor scheduling using an Artificial Bee Colony metaphor. The methods maintain a threshold coverage level. The first method uses a fitness measure aimed at prolonging the network lifetime and the second method combines network lifetime with coverage. Both methods run until the coverage level fails to meet a threshold. Experiments show that both methods produce extended network lifetime. Comparisons are made with a method in which awake and sleep times are set randomly.

ACKNOWLEDGEMENTS

I am heartily thankful to my adviser, Dr. Kendall Nygard for his encouragement, guidance and support from the initial to the final level of this paper. I would like to thank Dr. Kenneth Magel and Dr. Jeremy Jackson for being a part of my supervisory committee.

I express my warm thanks to Gretchen Young for being a very understanding manager at my work place.

I would like to dedicate this paper to my loving husband Mr. ElamPiraii Thamizh Pandian for his encouragement and motivation to complete this project.

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1. INTRODUCTION

Wireless sensor networks (WSNs) configured for applications like surveillance typically have a large number of sensors that are deployed across a given geographical area. There are many applications, especially for sensing and analyzing information for wildlife management and in military conflict areas. Operations with sensor networks involve a number of special issues, including limited battery capacity, power-consuming and limited reach, maintaining radio-frequency communication, large-size of deployment area, and large number of nodes [1].

Once deployed in fixed locations, percentages of coverage and network duration are major issues [2]. In some cases, the area sensed by the layout of the sensors within a geographical area can provide excessive or redundant coverage. If awake and sleep modes can be controlled for each sensor, there is potential for selectively setting these modes over time in such a way that network lifetime is extended while always maintaining adequate coverage. In some applications only partial coverage is necessary to maintain adequate network performance. Allowing partial coverage can also improve the network's lifetime. The logic depends on a specified partial coverage level being adequate [1]. Our work addresses the interplay between maintaining adequate coverage and conserving energy to achieve extended network lifetime.

In this paper, we develop and evaluate two heuristic methods for sensor scheduling and coverage using an Artificial Bee Colony (ABC) metaphor [2-4]. The methods determine exactly which sensors should be awake or asleep for discrete time intervals. We refer to the two heuristics as follows:

- The Long life time model (LL)
- The High Coverage and Long Lifetime model (HCLL)

In the LL method, the fitness value calculated at each iteration considers only remaining battery power of the individual sensors. In the HCLL method, the fitness value is based on a combination of the coverage level and the remaining battery life.

The methods accept input parameters for number of sensors, percentage of sensors awake, sensor radius, sensing range, battery power, energy consumption per time interval and required threshold coverage. In the experiments the sensors are deployed randomly in a given geographical area and schedules are produced iteratively until the required threshold coverage can no longer be met. In the visualization display of our graphical user interface (GUI), the awake and asleep sensors appear in green and red respectively, and sensors that have failed or have an exhausted battery appear in light yellow. The GUI displays the network coverage, number of time intervals that the network was performing adequately, and total time taken to compute the solution. We compare the experimental results of the two methods and also compare with a method in which the awake and sleep times are set randomly. Results indicate that the ABC approach is promising for sensor scheduling problems.

The rest of the paper is organized as follows. Section 2 discusses the related works. Section 3 provides the problem statement and the ABC algorithm. Section 4 describes simulation results and section 5 discusses conclusions and future work.

2. LITERATURE REVIEW

In wireless sensor networks, considerable work has been done on coverage problems, less on scheduling problems, and very little specifically on extending network lifetime. Within coverage there are mainly three categories: target coverage, breach coverage, and area coverage. Target coverage is specific to the issue of the sensors maximizing their coverage of a set of targets, while breach coverage refers to minimizing the number of targets left uncovered. Area coverage, the focus of our work, concerns covering a geographical area. In area coverage, the sensors can be concerned with detecting such things as movement, radiation, temperature, or presence of a chemical. Controlling the positions of the sensors is a basic approach in coverage problems.

Dynamic deployment of the sensors in a WSN is an active research topic. For example, in [5] an ABC heuristic is employed and in [6] a virtual force algorithm is used for dynamic deployment of sensors. The work reported in [7] divides a region into grid cells and seeks to leave only one sensor active in each cell. In most cases, the sensors in a WSN are operated by battery power, although some may use solar panels. In applications like surveillance, batteries cannot be easily replaced, and improvements in battery technology occur slowly. With today's technology, conserving energy is important in a WSN.

Various algorithms have been proposed for scheduling sleep and wake modes for sensors, such as the work reported in [8] that uses integer linear programming.

In our work we used an ABC algorithm for scheduling the sleep/awake cycle of sensors.

3. PROBLEM DESCRIPTION

We implemented two heuristic methods for sensor scheduling and coverage using an Artificial Bee Colony metaphor. We also implemented a method in which sleep and wake times are set randomly. The methods were implemented in the C# language in visual studio 2012 IDE and evaluated on a suite of test problems.

3.1. The Artificial Bee Colony Metaphor

Swarm intelligence methods for problem solving are inspired by massively parallel animal-to-animal interactions that produce emergent intelligent behavior. Examples include birds forming flocks, animals forming herds, fish forming schools, and ants collectively exploiting a food source. Heuristics based on swarm intelligence approaches have been used to provide excellent solutions to a wide variety of combinatorial optimization problems.

Honey bee swarms exhibit collective intelligence through distributed evidence gathering and processing for their selecting of sites for nests and in their foraging for nectar. Our search strategies basically follow the behaviors used in foraging for nectar. Fundamentally, bees that find rich food sources exhibit behaviors that result in exploiting them (positive feedback), while food sources that are less desirable to begin with or become diminished are not exploited (negative feedback).

Karaboga first presented the ABC method [2, 3, and 4]. In the method, there are three bee groups called the employed, onlooker, and scout bees. Employed bees explore, find and identify with a food source.

They carry out a “waggle dance” at the hive. The number of cycles in a dance is correlated with the richness of the food source with which the employed bee is associated.

The onlooker bees observe the dances, select a given food source with a probability in proportion to its richness level, and begin exploiting the source. When the richness of a food source becomes significantly diminished, it is abandoned, and some bees are converted into scouts to identify new food sources from scratch.

3.2. The Sensor Scheduling Methods

Following the bee colony metaphor, candidate solutions to the sensor scheduling problem play the role of nectar sources. A given number of artificial bees CS are specified. A given number of sensors are to be deployed in the network, and a specified percentage of them must be awake to provide adequate coverage. A portion of the bees, nominally half of them or CS/2, are designated to be employed bees. Initially each employed bee is provided with a randomly generated set of NS sensors with the percentage PER of them set to awake state.

Figure 1 and Figure 2 illustrates the steps involved in HCLL and LL models respectively. First, a set of sensors will be assigned to each employee bee and the nectar level proxy will be evaluated.

In the Long Lifetime or LL model [Figure 1]:

Nectar level proxy = Normalized total energy level of the candidate solution = the remaining battery lifetime of the awake sensors, summed over all that are awake.

In the High Coverage and Long Life time or HCLL model [Figure 2]:

Nectar level proxy =α*Normalized total energy level of the candidate solution + (1-α)*Normalized coverage area of the nodes in the candidate solution.

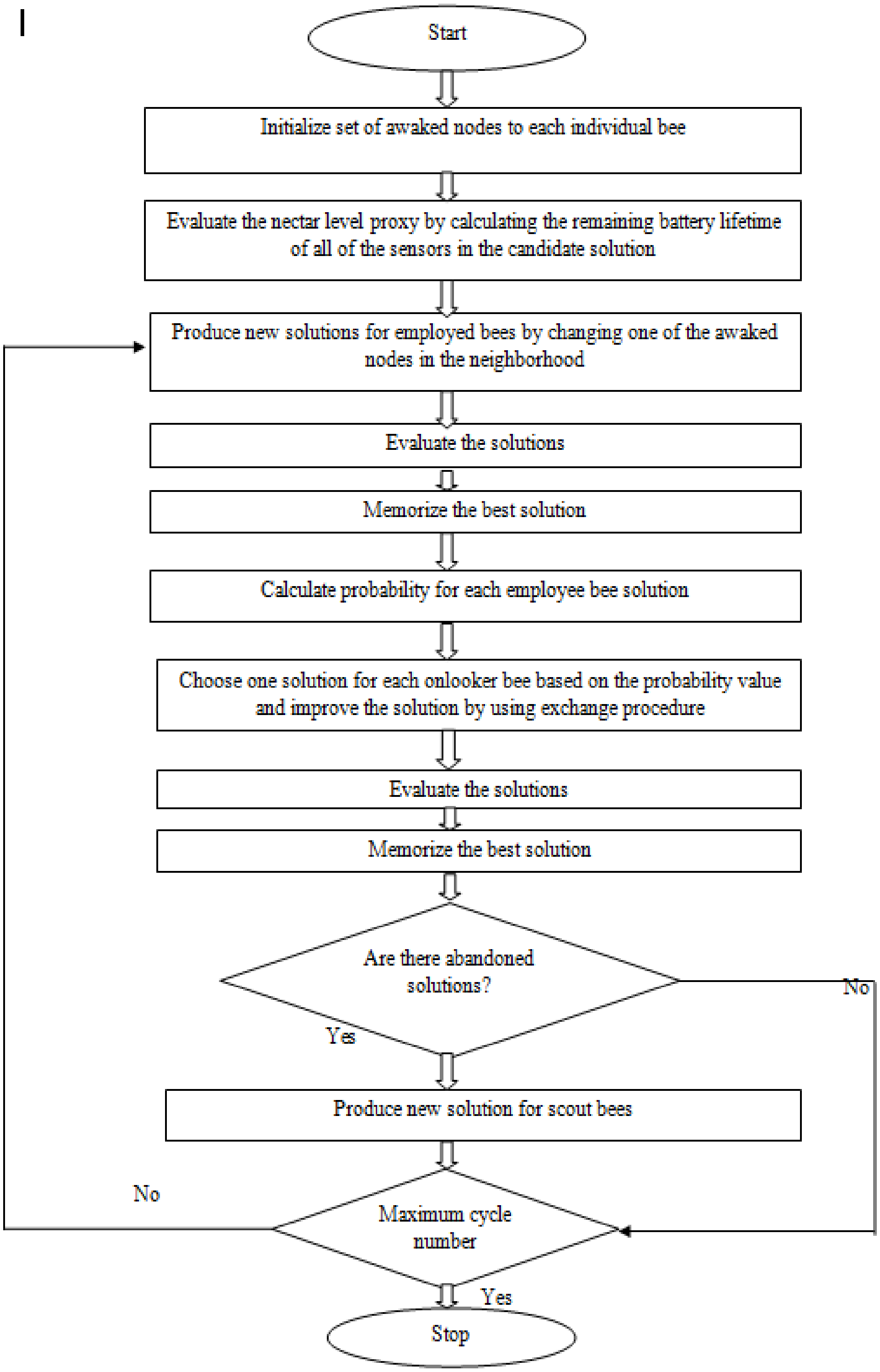


Figure 1. Flowchart for LL Model

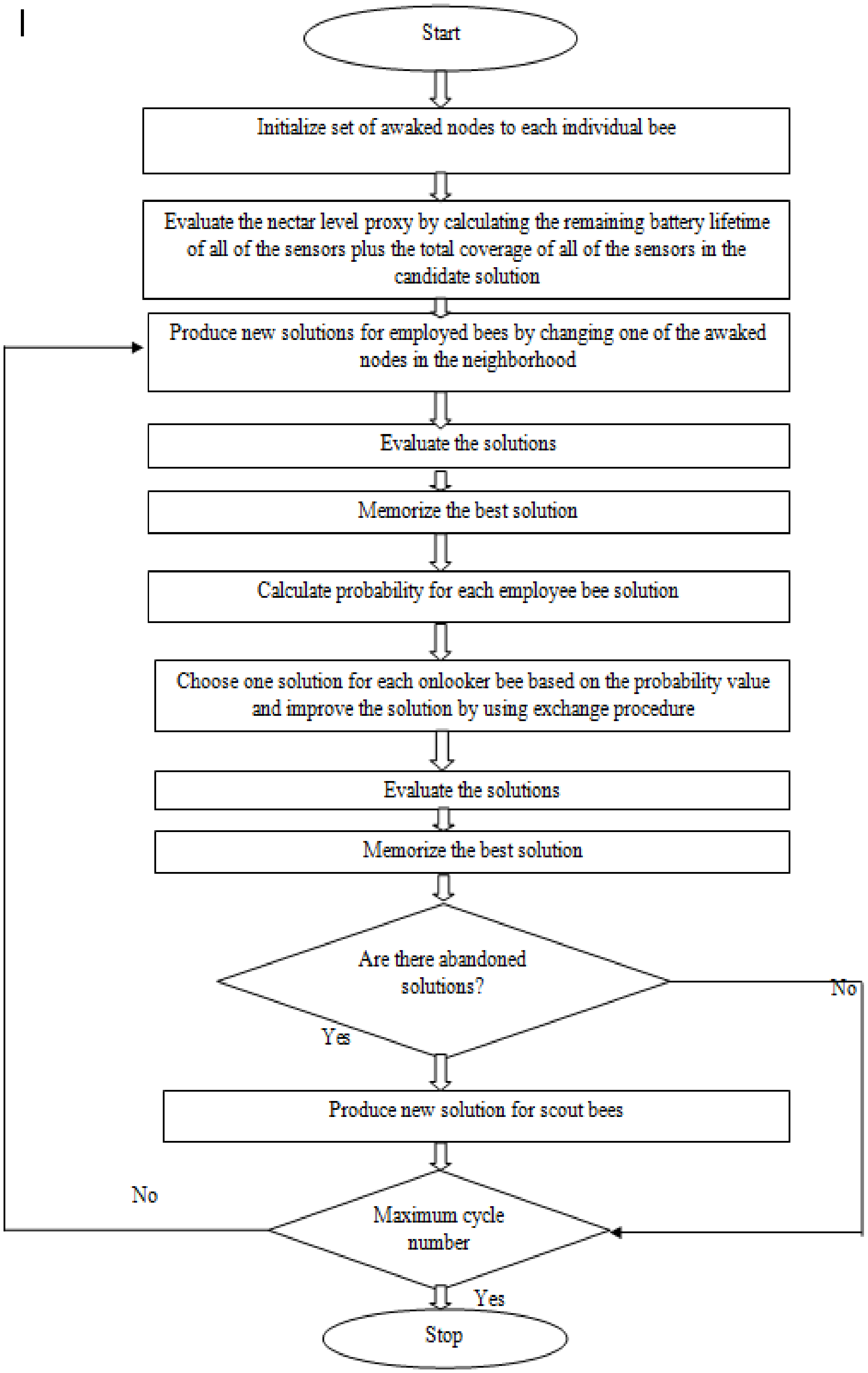
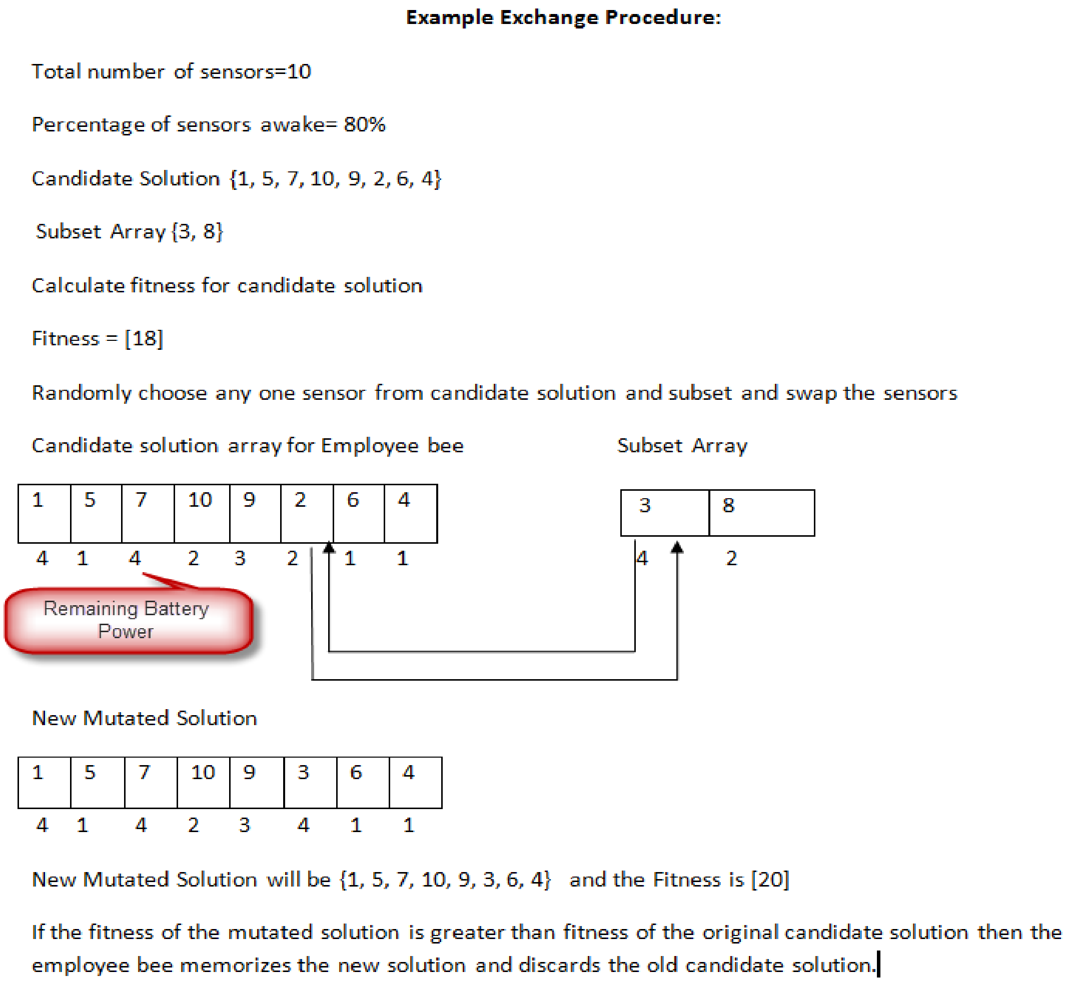


Figure 2. Flowchart for HCLL Model

Each employee bee carries out a local search designed to improve the solution that it was given, and memorizes the best solution it has identified. As shown in Figure 3, the candidate solution array consist of the set of sensors that are picked by the employee bee based on the input parameters. The subset array consist of set of sensors that are not selected by the employee bee. The local search consists of exchanging sensors in the candidate solution array with the sensor in the subset array, evaluating the resultant performance, and checking for an improved solution.



Example Exchange Procedure:

Total number of sensors=10

Percentage of sensors awake= 80%

Candidate Solution {1, 5, 7, 10, 9, 2, 6, 4}

Subset Array {3, 8}

Calculate fitness for candidate solution

Fitness = [18]

Randomly choose any one sensor from candidate solution and subset and swap the sensors

Candidate solution array for Employee bee

1	5	7	10	9	2	6	4
4	1	4	2	3	2	1	1

Subset Array

3	8
4	2

New Mutated Solution

1	5	7	10	9	3	6	4
4	1	4	2	3	4	1	1

New Mutated Solution will be {1, 5, 7, 10, 9, 3, 6, 4} and the Fitness is [20]

If the fitness of the mutated solution is greater than fitness of the original candidate solution then the employee bee memorizes the new solution and discards the old candidate solution.

Figure 3. Exchange Procedure

That is, the employee bee randomly pick one sensor for example sensor 2 [Figure 3] in the candidate solution and exchange it with another sensor for example sensor 3 [Figure 3] in the subset. This forms a new mutated solution. The fitness of this new mutated solution is calculated based on the energy levels of each sensors in the solution array. The new mutated solution will be memorized if the fitness of the new mutated solution is greater than the fitness of the original candidate solution. Otherwise, a trial counter is incremented if the original Candidate solution array is not improved further.

After the employee bee phase, probability value is calculated for each employee bee’s solution.

$$P_i = \frac{f(x_i^*)}{\sum_{j=1}^{n} f(x_j^*)} \quad \text{--------------} \ (1)$$

In equation (1), the population of employed bees is indexed by i, the candidate solution is x_i for each bee, and the nectar level for each bee is f (x_i).

The portion of bees not designated as employees are assigned to be Onlooker bees. Any value from 0.1 to 1 is randomly assigned to each onlooker bee as nectar value. Based on its own nectar value, the onlooker bee selects their base solutions from employee bee’s probability value. Each Onlooker bee uses an exchange procedure to swap sensors between the candidate solution and the subset to seek improved solutions.

If a given number of failed trial attempts to improve the base solution occurs, it is abandoned and the corresponding employed bee is re dispatched as a scout and given a new randomly chosen solution from scratch. The best solution found thus far is memorized and retained.

The procedure is run for a specified number of iterations, with the result being the schedule of awake and sleeping sensors.

3.3. Random Scheduling Model

In addition to HCLL and LL models, we also developed and evaluated a Random Scheduling (RS) model. We compare the results of HCLL and LL with the RS model to show that both of our models are effective and increases lifetime of the WSN.

In this model, the percentage of sensor needs to be turned ON are chosen randomly without considering the remaining battery life of sensor and network coverage.

The RS model algorithm steps are explained below.

Step 1: Initialize parameters

Step 2: Randomly choose the set of sensors to be turned ON

Step 3: Calculate the coverage percentage PER

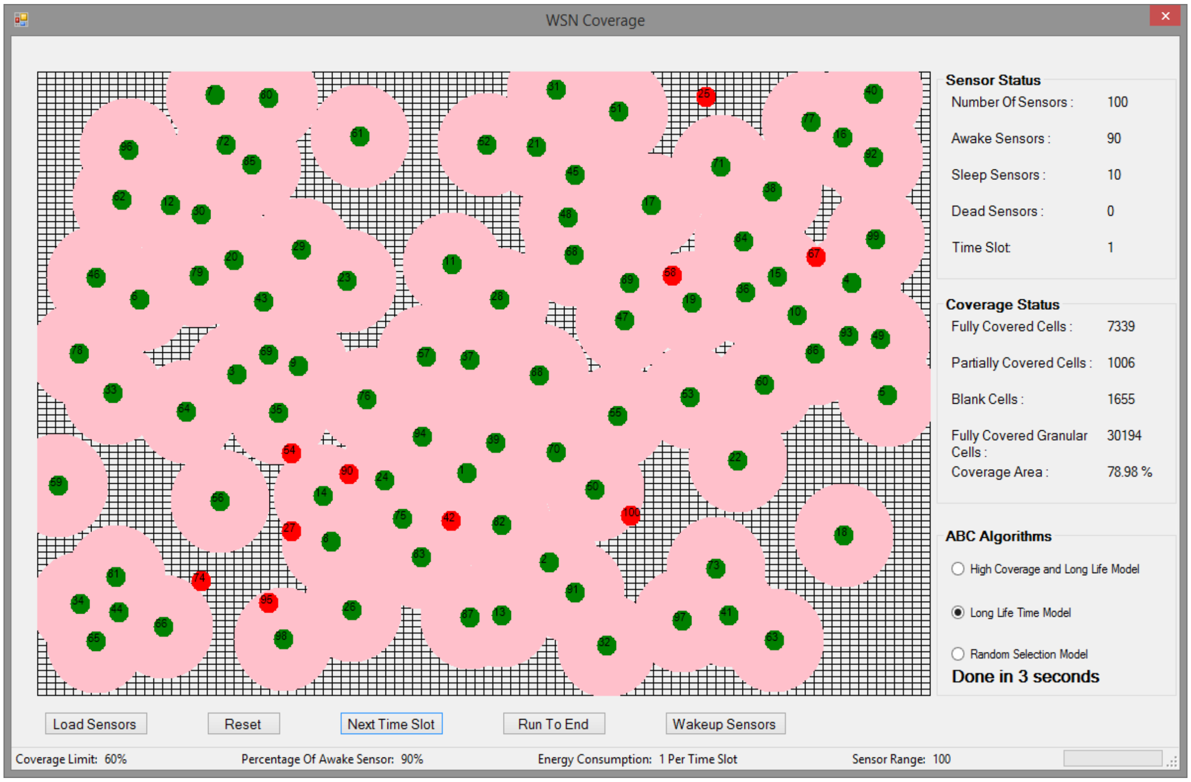
Step 4: If PER >= Threshold coverage (TC) then increment the time interval and go to step 2 else go to step 5

Step 5: Stop

For each interval, the RS model randomly chooses the sensors to be turned ON until the model fails to provide the threshold coverage. Since there are no iterations involved to increase the network lifetime and coverage, the computation time will be much faster when compared to HCLL and LL.

4. EXPERIMENTAL RESULTS

In our experiments, we defined a rectangular geographical area 900*600 and a network with n stationary sensors deployed randomly in a two dimensional area. Each sensor has a known sensing radius, all of which are the same size. Battery power is set to be equal for all sensors. Figure 4 illustrates the Graphical User Interface for the application.



Sensor Status
Number Of Sensors : 100
Awake Sensors : 90
Sleep Sensors : 10
Dead Sensors : 0
Time Slot 1

Coverage Status
Fully Covered Cells : 7339
Partially Covered Cells : 1006
Blank Cells : 1655
Fully Covered Granular Cells : 30194
Coverage Area : 78.98 %

ABC Algorithms
○ High Coverage and Long Life Model
● Long Life Time Model
○ Random Selection Model
Done in 3 seconds

Coverage Limit: 60%
Percentage Of Awake Sensor: 90%
Energy Consumption: 1 Per Time Slot
Sensor Range: 100

Figure 4. GUI for WSN Coverage Algorithm

In Figure 4, the small red circles are sleeping sensors while the small green circles are awake. The sensing radius is illustrated, providing insight into sensor coverage. There are 10000 cells in our geographical area with a single cell of size 9*6. If the sensing radius covers a cell fully then that cell is counted as Fully Covered Cell. If the sensing radius covers only part of a cell then that cell is counted as Partially Covered Cell.

All the Partially Covered Cell is then further divided in to 54 fine granular cells of size 1*1 and the total number of fine granular cell is 540000 if all the cells are marked partially covered cell in the geographical area.

The coverage area is calculated by finding the total number of fully covered fine granular cells divided by 54 and adding the result to the total number of fully covered cells.

To find the coverage percentage, the coverage area is divided by the total cells in the geographic area.

There are options for specifying a model and running it to completion or incrementing and illustrating the solution step by step.

In our experiments we set battery life of 10 units per sensor, and a coverage range of 100 units. A sensor that is awake for one time period consumes one unit of battery power, minimum area coverage limit: 60% when total number of sensor is 100 and minimum area coverage limit: 45% when total number of sensor is 75. We set the colony size at 20 bees, with 10 employee and 10 Onlooker bees. The trial limit set for the bees is set to 100 and the iteration set to 100000.

Various percentages of mandatory awake sensors were evaluated for HCLL, LL and RS algorithms and the results are automatically written in excel files.

4.1. Test Case 1: When Percentage of Sensor Awake is 90

For test case 1 we present the statistical data for HCLL, LL and RS algorithms when scheduling 90% sensors ON.

4.1.1. HCLL, LL and RS for 90% Sensors ON for 100 sensors

The following input parameters are used. Total number of sensors =100, Percentage of sensors Awake= 90 %, Minimum Coverage area limit =60%.

This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit.

From the results of Table 1, it is very clear that both of our models provides threshold coverage until T=11 and Random generator provides until T=10 and fails at T=11 When total number of sensors is 100 and 90% of sensors are scheduled to turn ON.

Table 1. Coverage statistics comparison for 100 sensors when 90 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	76.64±0.78	76.548±0.70	75.96±1.08
2	76.50±0.72	76.832±0.77	76.76±0.74
3	76.26±0.97	76.575±0.58	76.51±0.99
4	75.80±1.05	76.148±0.95	76.31±1.14
5	76.53±0.83	76.28±1.05	76.05±1.21
6	76.61±0.66	76.827±0.34	76.58±1.09
7	76.36±1.02	76.554±0.91	76.63±0.93
8	76.52±0.89	76.421±0.96	76.23±1.16
9	76.42±0.97	75.504±1.10	76.52±1.07
10	76.87±0.93	76.249±0.89	76.68±1.17
11	75.44±0.98	76.181±0.51	55.12±1.09
12	15.90±0.94	13.31±0.44	--

The Figure 5 explains that both of our models HCLL and LL increases life time of our WSN to 11 when compared with RS model which fails at T=11.

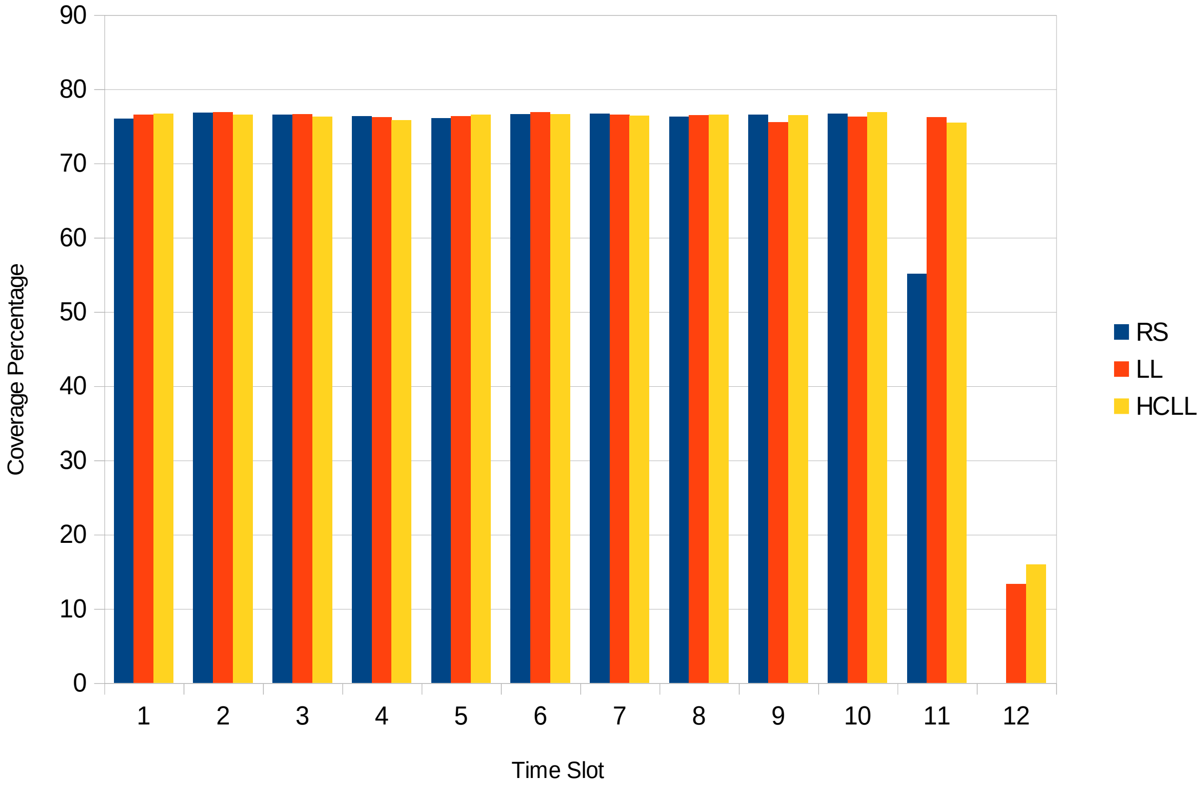


Figure 5. Coverage when 90% of the sensors are awake for 100 sensors

4.1.2. HCLL, LL and RS for 90% Sensors ON for 75 sensors

The following input parameters are used. Total number of sensors =75, Percentage of sensors Awake= 90 %, Minimum Coverage area limit =45%.

This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit.

From the results of Table 2, it is very clear that both of our models HCLL and LL provides threshold coverage until T=11 and RS model provides until T=10 and fails at T=11 When total number of sensors is 75 and 90% of sensors are scheduled to turn ON.

Table 2. Coverage statistics comparison for 75 sensors when 90 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	70.07±1.09	65.48±1.26	65.68±1.14
2	69.09±1.63	65.81±1.03	65.59±1.24
3	69.55±0.98	65.72±1.26	65.78±0.79
4	69.99±1.10	65.64±1.10	66.21±1.12
5	69.97±1.22	65.27±1.09	66.13±0.81
6	70.21±1.10	66.02±1.09	65.84±1.03
7	69.40±1.39	65.87±1.55	65.58±1.28
8	70.25±1.14	65.84±1.04	65.77±1.24
9	69.68±1.36	65.77±1.01	65.88±0.87
10	69.80±1.06	66.16±1.28	65.84±1.21
11	69.77±1.27	66.19±1.36	47.23±1.53
12	17.18±0.45	17.21±0.59	25.64±1.59

The Figure 6 explains that both of our models HCLL and LL increases life time of our WSN to 11 when compared with RS model which fails at T=11.

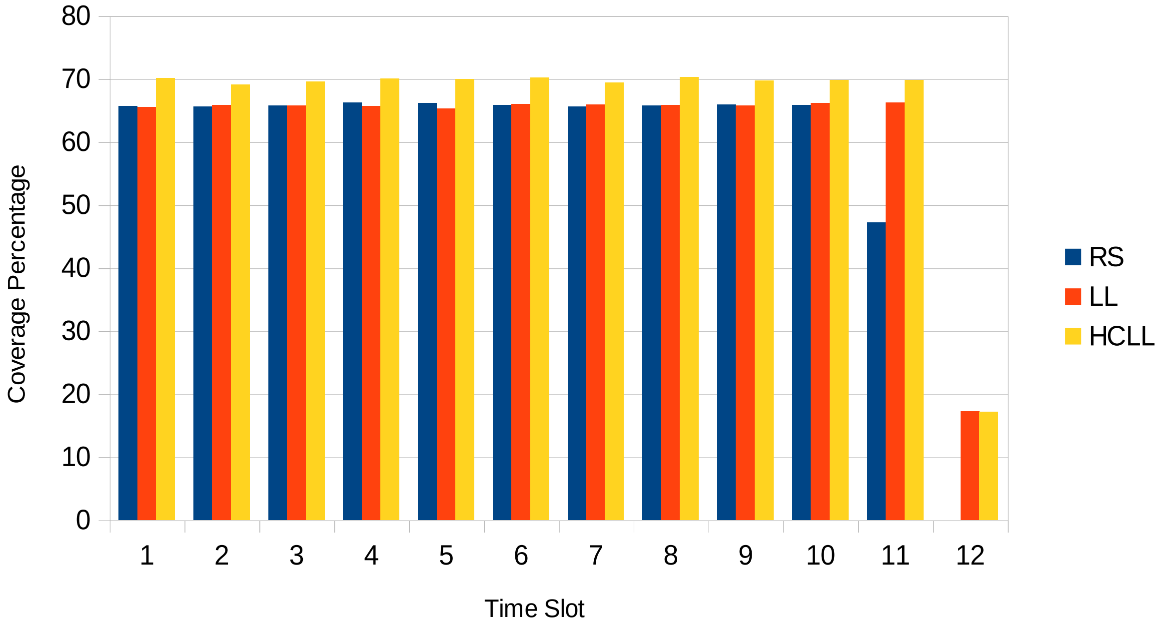


Figure 6. Coverage when 90% of the sensors are awake for 75 sensors

4.2. Test Case 2: When Percentage of Sensor Awake is 80

For test case 2 we present the statistical data for HCLL, LL and RS algorithms when scheduling 80% sensors ON.

4.2.1. HCLL, LL and RS for 80% Sensors ON for 100 sensors

The following input parameters are used. Total number of sensors =100, Percentage of sensors Awake= 80 % Minimum Coverage area limit =60%. This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit.

From the results of Table 3, it is very clear that both of our models HCLL and LL provides threshold coverage until T=12 and RS model provides until T=11 and fails at T=12 When total number of sensors is 100 and 90% of sensors are scheduled to turn ON.

Table 3. Coverage statistics comparison for 100 sensors when 80 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	72.28±1.25	72.33±0.92	71.50±1.30
2	72.58±1.22	72.87±10.87	72.67±1.57
3	71.59±1.07	72.26±1.61	72.49±1.02
4	72.27±1.43	71.78±1.18	71.93±1.38
5	72.23±1.19	72.81±0.82	72.63±1.04
6	72.31±0.77	72.10±1.08	72.56±1.12
7	71.71±1.51	72.60±0.72	72.78±1.41
8	72.75±0.70	72.93±1.11	72.91±0.98
9	72.85±0.78	72.20±1.42	72.86±1.06
10	72.48±1.86	72.45±0.96	71.76±1.15
11	73.31±1.01	72.76±1.07	67.84±1.22
12	70.73±0.62	73.07±0.53	55.32±1.44
13	46.52±1.70	44.83±0.93	--

The Figure 7 explains that both of our models HCLL and LL increases life time of our WSN to 12 when RS model fails at T=12.

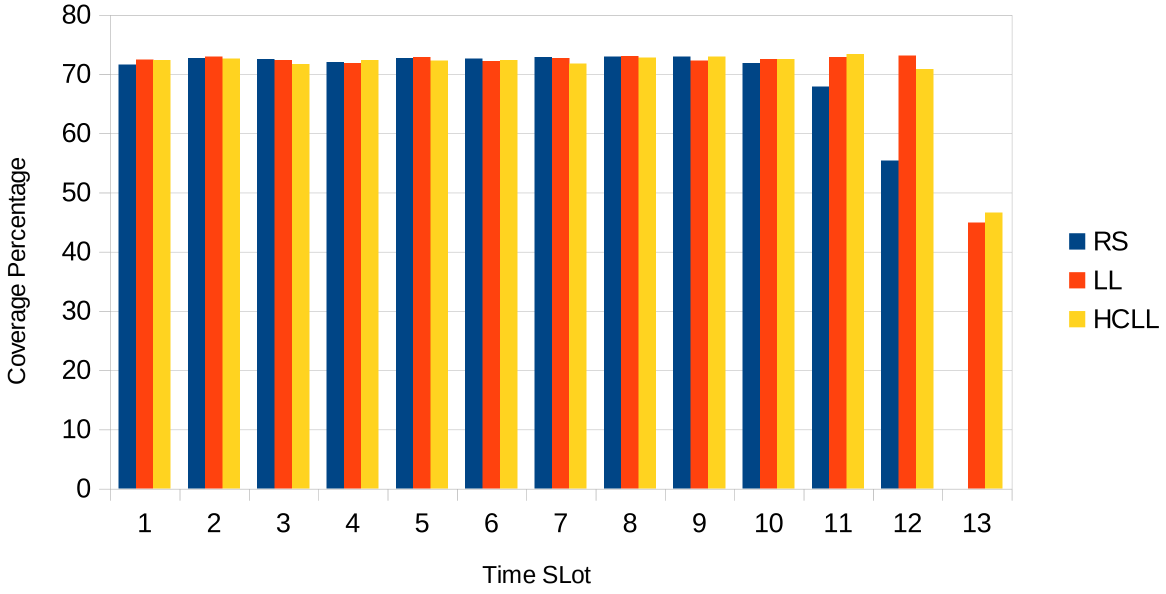


Figure 7. Coverage when 80% of the sensors are awake for 100 sensors

4.2.2. HCLL, LL and RS for 80% Sensors ON for 75 sensors

The following input parameters are used. Total number of sensors =75, Percentage of sensors Awake= 80 % Minimum Coverage area limit =45%. This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit.

From the results of Table 4, it is very clear that both of our models HCLL and LL provides threshold coverage until T=12 and RS model provides until T=11 and fails at T=12 When total number of sensors is 75 and 90% of sensors are scheduled to turn ON.

Table 4. Coverage statistics comparison for 75 sensors when 80 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	67.94±1.53	60.52±1.30	61.01±1.05
2	67.44±1.23	60.20±1.29	60.94±0.82
3	67.29±1.35	60.61±1.06	60.67±1.76
4	67.22±1.55	60.65±1.20	59.88±1.44
5	68.08±0.93	60.23±1.12	60.47±1.25
6	66.66±1.51	60.17±1.03	60.70±1.19
7	67.27±0.90	60.29±1.17	60.58±1.32
8	67.24±1.31	60.53±1.19	60.53±1.26
9	67.09±2.08	60.68±1.21	61.03±1.28
10	67.34±1.65	60.45±1.18	61.24±1.08
11	67.72±1.13	60.62±1.21	56.32±1.60
12	67.80±1.20	60.65±1.40	44.94±2.01
13	35.24±1.18	35.53±0.84	30.74±1.88

The Figure 8 explains that both of our models HCLL and LL increases life time of our WSN to 12 when the RS model fails at T=12.

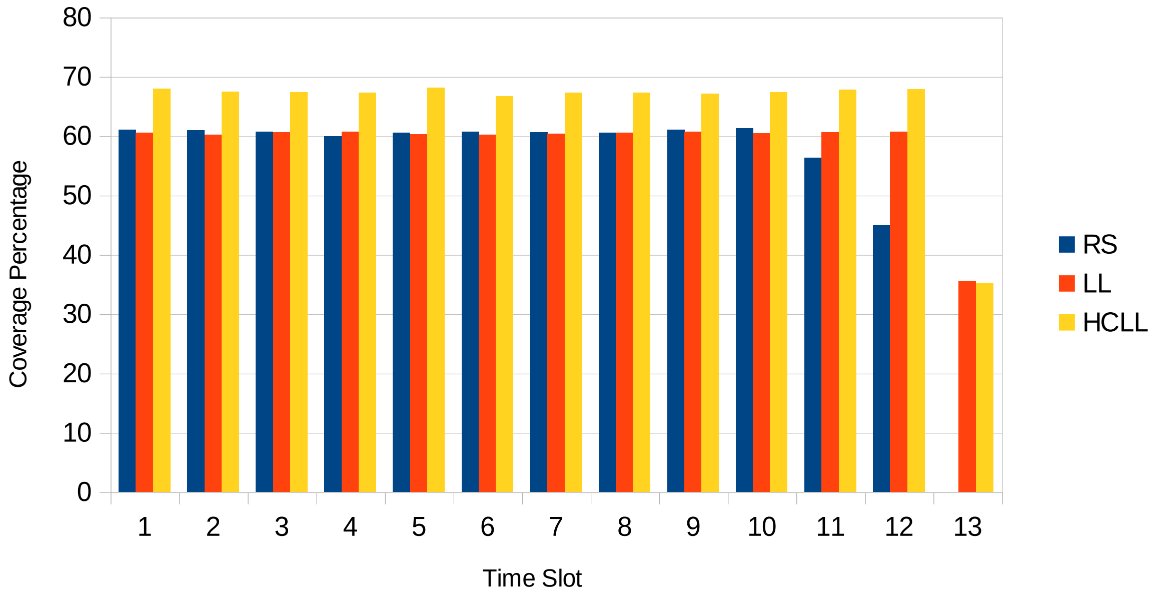


Figure 8. Coverage when 80 % of the sensors are awake for 75 sensors

4.3. Test Case 3: When Percentage of Sensor Awake is 70

For test case we are present the statistical data for HCLL, LL and RS algorithms when scheduling 90% sensors ON.

4.3.1. HCLL, LL and RS for 70% Sensors ON for 100 sensors

The following input parameters are used. Total number of sensors =100, Percentage of sensors Awake= 70 % Minimum Coverage area limit =60%. This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit which is 60%.

From the results of Table 5, it is very clear that both of our models HCLL and LL provides threshold coverage until T=14 and RS model provides until T=13 and fails at T=14 When total number of sensors is 100 and 70% of sensors are scheduled to turn ON.

Table 5. Coverage statistics comparison for 100 sensors when 70 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	65.62±1.41	65.14±1.11	65.93±1.30
2	65.16±1.26	65.22±1.49	66.11±1.69
3	64.54±1.16	65.54±1.15	66.11±1.41
4	66.22±1.44	64.45±1.71	65.45±1.02
5	65.45±1.42	65.67±1.35	64.84±1.80
6	66.04±1.39	65.72±0.81	66.12±1.27
7	65.81±1.65	65.76±1.04	65.58±1.34
8	65.70±1.56	65.09±1.48	64.65±1.62
9	65.20±1.24	65.30±1.18	65.53±1.70
10	65.49±1.20	65.50±1.19	65.12±1.17
11	65.40±1.57	66.10±1.25	64.10±1.47
12	65.33±1.18	65.49±1.38	59.67±1.99
13	65.45±1.29	66.10±0.53	52.92±2.39
14	61.97±1.36	64.81±1.12	42.47±1.90
15	29.65±1.46	25.60±0.53	--

The Figure 9 explains that both of our models HCLL and LL increases life time of our WSN to 14 when the random RS fails at T=12.

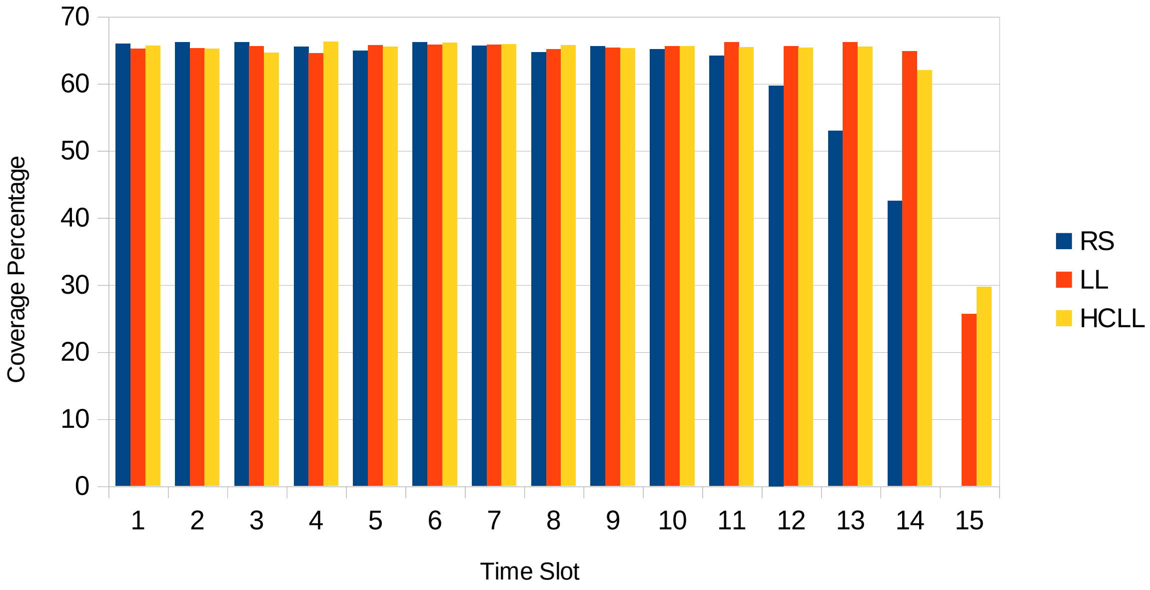


Figure 9. Coverage when 70 % of the sensors are awake for 100 sensors

4.3.2. HCLL, LL and RS for 70% Sensors ON for 75 sensors

The following input parameters are used. Total number of sensors =75, Percentage of sensors Awake= 70 % Minimum Coverage area limit =45%. This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit which is 45%.

From the results of Table 6, it is very clear that both of our models HCLL and LL provides threshold coverage until T=14 and RS model provides until T=11 and fails at T=12 When total number of sensors is 75 and 70% of sensors are scheduled to turn ON.

Table 6. Coverage statistics comparison for 75 sensors when 70 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	**RS**
1	64.90±1.95	55.03±1.46	54.08±1.30
2	64.52±1.33	55.20±1.00	54.68±1.55
3	65.42±1.64	54.30±1.37	54.49±0.86
4	64.21±2.58	53.78±0.91	54.21±1.26
5	64.97±1.25	55.13±1.65	55.45±1.01
6	64.26±0.95	54.54±1.15	55.09±1.22
7	62.13±3.03	55.46±0.82	54.57±0.92
8	64.82±1.09	54.17±1.77	54.33±1.12
9	64.32±2.02	54.98±1.31	55.23±1.25
10	64.25±1.70	55.08±0.88	55.43±0.94
11	65.60±1.51	54.43±0.82	53.89±1.41
12	64.77±1.16	53.70±1.10	49.48±1.39
13	64.30±1.34	54.74±1.39	42.36±2.32
14	64.56±1.27	54.30±0.94	38.12±1.01
15	28.92±1.10	27.72±0.65	--

The Figure 10 explains that both of our models HCLL and LL increases life time of our WSN to 14 when the RS model fails at T=12.

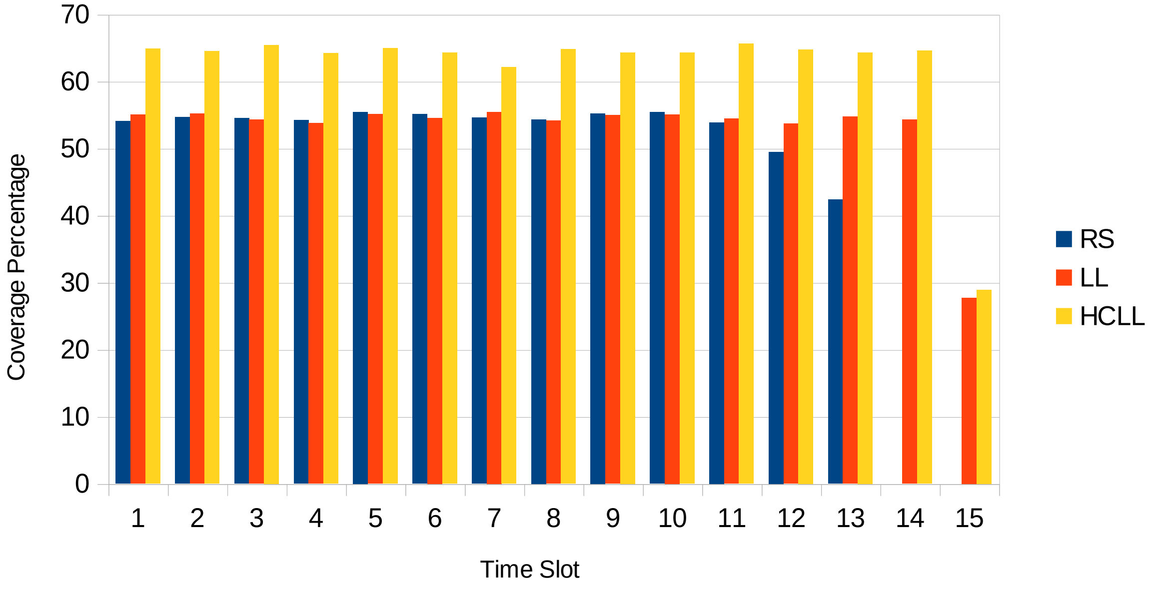


Figure 10. Coverage when 70 % of the sensors are awake for 75 sensors

4.4. Test Case 4: When Percentage of Sensor Awake is 60

For test case 4 we present the statistical data for HCLL, LL and RS algorithms when scheduling 60% sensors ON.

4.4.1. HCLL, LL and RS for 60% Sensors ON

The following input parameters are used. Total number of sensors =100, Percentage of sensors Awake= 60 %, Minimum coverage area limit =60%.This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit which is 60%.

From the results of Table 7, it is very clear that both of our models HCLL and LL provides threshold coverage until T=15 and RS model provides until T=11 and fails at T=12 When total number of sensors is 100 and 60% of sensors are scheduled to turn ON.

Table 7. Coverage statistics comparison for 100 sensors when 60 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	RS
1	62.69±3.39	60.51±1.17	61.01±1.16
2	60.90±1.40	60.93±0.99	61.13±0.96
3	59.41±0.77	60.52±1.44	60.30±1.39
4	60.68±0.98	60.79±0.98	60.54±1.58
5	60.18±1.22	60.92±0.99	60.49±0.87
6	60.11±1.04	61.33±1.28	60.51±0.71
7	60.42±1.29	60.47±0.86	61.20±0.58
8	60.56±0.82	60.93±1.28	60.78±1.19
9	60.60±1.10	60.83±1.55	60.74±1.79
10	61.44±0.95	60.52±1.62	60.51±0.96
11	60.42±1.15	61.09±1.57	60.00±1.26
12	60.81±1.77	60.30±0.81	58.71±0.81
13	61.63±1.12	61.33±0.91	56.93±1.82
14	60.56±1.19	60.89±1.41	52.42±1.67
15	60.22±1.25	60.06±0.61	48.31±1.60
16	57.26±1.58	61.33±1.10	--

The Figure 11 explains that HCLL model increases life time of our WSN to 15 and model increases life time of our WSN to 16 when RS model fails at T=13.

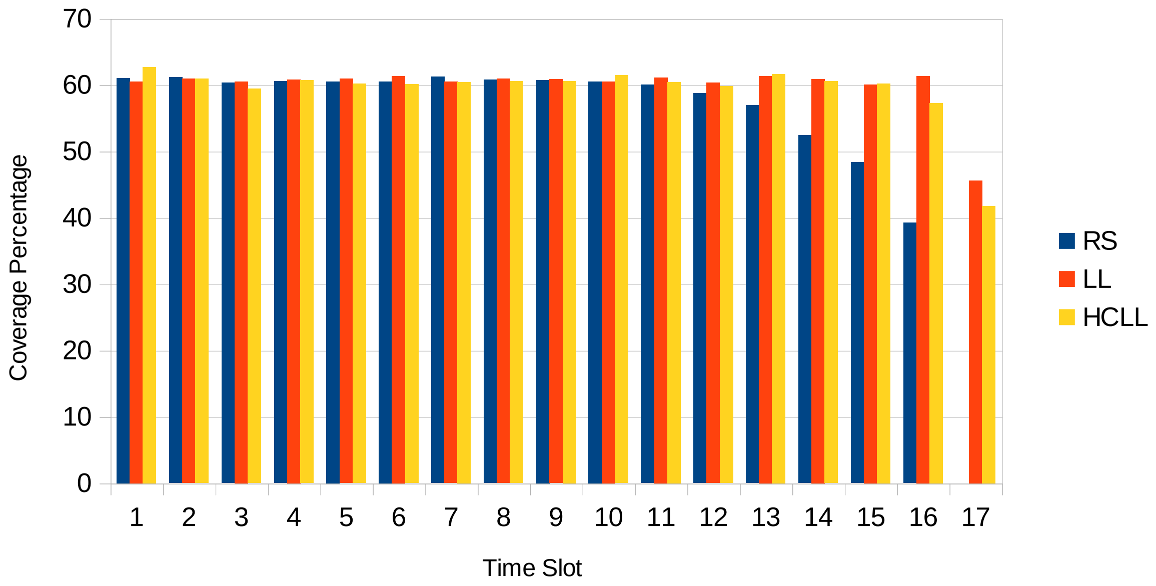


Figure 11. Coverage when 60 % of the sensors are awake for 100 sensors

4.4.2. HCLL, LL and RS for 60% Sensors ON for 75 sensors

The following input parameters are used. Total number of sensors =100, Percentage of sensors Awake= 60 %, Minimum coverage area limit =45%.This test case is performed for several time slots until the model fails to provide our minimum threshold coverage limit which is 45%.

From the results of Table 8, it is very clear that both of our models HCLL and LL provides threshold coverage until T=16 and RS model provides until T=11 and fails at T=14 When total number of sensors is 75 and 60% of sensors are scheduled to turn ON.

Table 8. Coverage statistics comparison for 75 sensors when 60 % sensors ON

Confidence Interval (Coverage %)			
Time Slot	**HCLL**	**LL**	RS
1	62.13±1.86	49.36±1.13	49.78±0.90
2	62.57±1.52	49.87±0.89	50.11±1.09
3	62.43±1.37	50.14±1.17	49.80±0.96
4	61.95±1.53	49.67±1.04	49.48±1.09
5	62.09±1.64	49.28±1.02	49.32±1.02
6	62.09±1.65	50.10±1.26	49.22±1.18
7	62.45±1.28	49.59±1.04	50.18±1.00
8	62.24±1.38	49.17±1.18	49.02±1.33
9	63.34±1.24	50.09±0.92	50.01±0.95
10	62.09±1.29	49.60±1.35	50.40±0.65
11	62.29±1.53	50.10±1.14	50.01±1.07
12	63.45±1.84	50.01±1.32	48.84±1.50
13	60.07±3.38	50.31±0.72	46.18±1.18
14	58.95±4.07	49.31±1.14	41.59±2.43
15	58.51±3.83	50.01±1.09	38.21±2.49
16	59.60±2.91	49.55±1.07	31.69±4.48
17	33.01±2.00	36.27±0.83	--

The Figure 12 explains that both of our models HCLL and LL increases life time of our WSN to 16 when the RS fails at T=13.

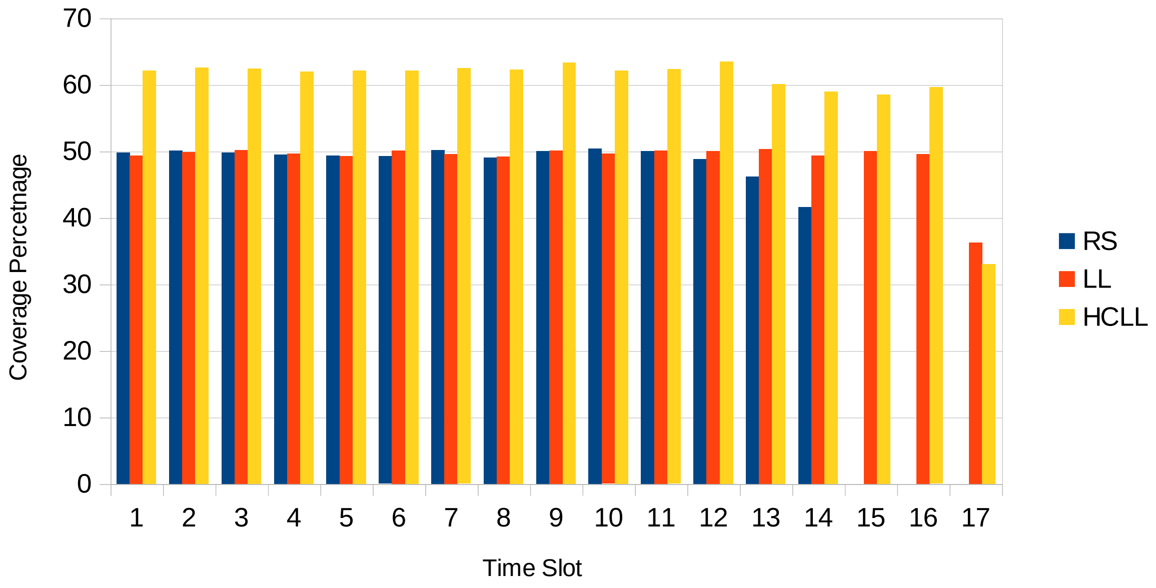


Figure 12. Coverage when 60 % of the sensors are awake for 75 sensors

4.5. Overall Performance

In this section we present the overall performance of two models High coverage and long lifetime (HCLL) and Long lifetime (LL) with the help of above conducted experiment results.

Network lifetime and average coverage percentage of our WSN for the test case with 100 sensors are shown in Table 9. From the results we can say that our HCLL and LL increases network lifetime when compared to RS model.

Table 9. Performance Comparison of HCLL, LL and RS for 100 Sensors

Total Number of sensors	**Percent of awake sensors**	**Network lifetime**			**Coverage Percentage**		
		RS	**LL**	**HCLL**	**RS**	**LL**	**HCLL**
100	60	11	16	15	60.66	60.43	60.80
	70	12	14	14	64.01	65.24	65.42
	80	11	12	12	71.99	72.26	72.51
	90	10	11	11	73.77	76.36	76.37

Figure 13 shows that network lifetime increases when percentage of sensors turned ON decreases.

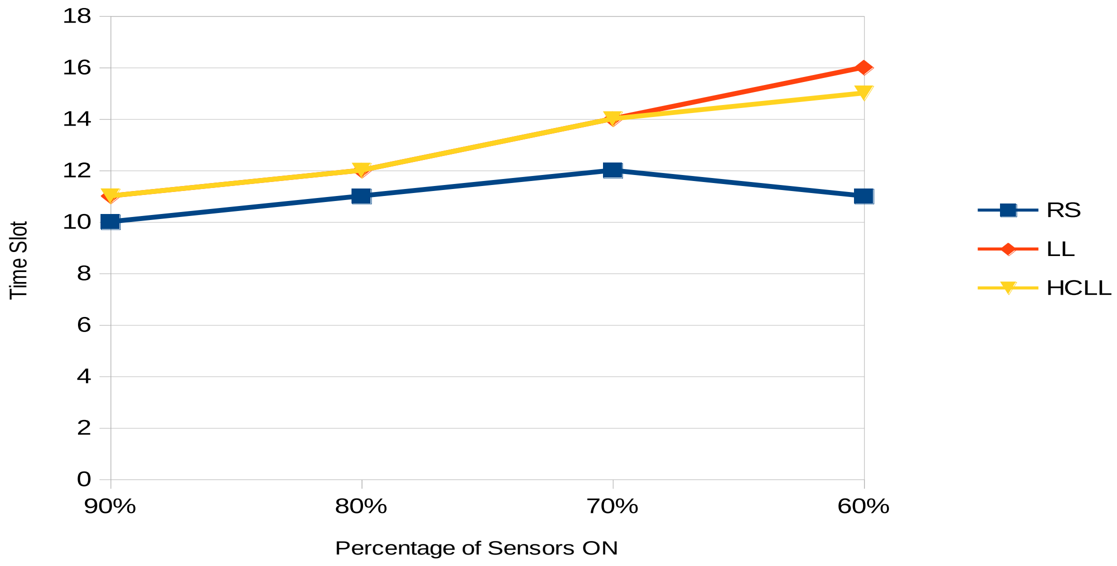


Figure 13. Network Lifetime Comparison for 100 Sensors

Figure 14 that shows that coverage percentage decreases when percentage of sensors turned ON decreases.

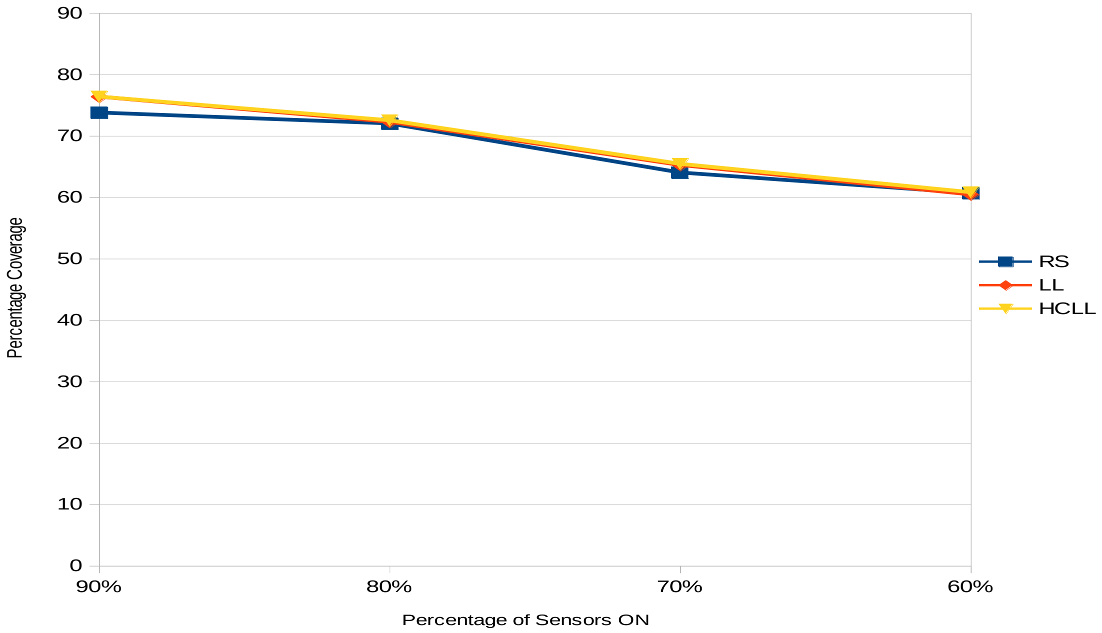


Figure 14. Coverage Percentage Comparison for 100 Sensors

From the above results it is clearly shown that HCLL and LL provides better coverage and increases lifetime of WSN than RS model.

Network lifetime and average coverage percentage of our WSN for the test case with 75 sensors are clearly shown in Table 10. From the results we can say that our HCLL and LL increases network lifetime when compared to RS model.

Table 10. Performance Comparison of HCLL, LL and RS for 75 Sensors

Total Number of sensors	**Percent of awake sensors**	**Network lifetime**			**Coverage Percentage**		
		RS	**LL**	**HCLL**	**RS**	**LL**	**HCLL**
75	60	13	16	16	49.41	49.76	61.64
	70	12	14	14	53.33	54.63	64.50
	80	11	12	12	59.02	60.47	67.43
	90	11	11	11	64.14	65.80	69.80

Figure 15 shows that network lifetime increases when percentage of sensors turned ON decreases.

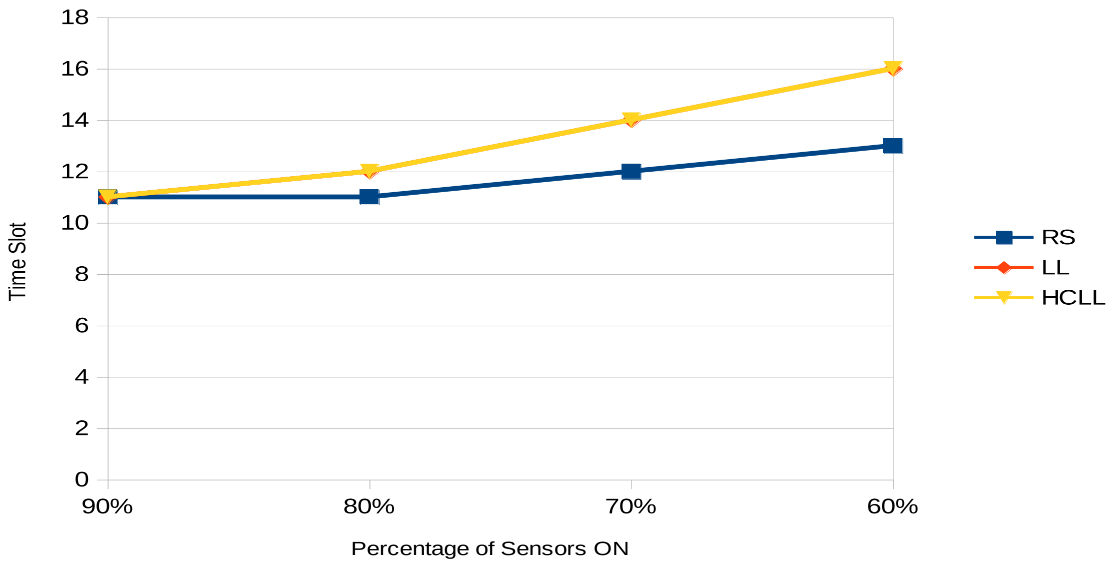


Figure 15: Network Lifetime Comparison for 75 Sensors

Figure 16 that shows that coverage percentage decreases when percentage of sensors turned ON decreases.

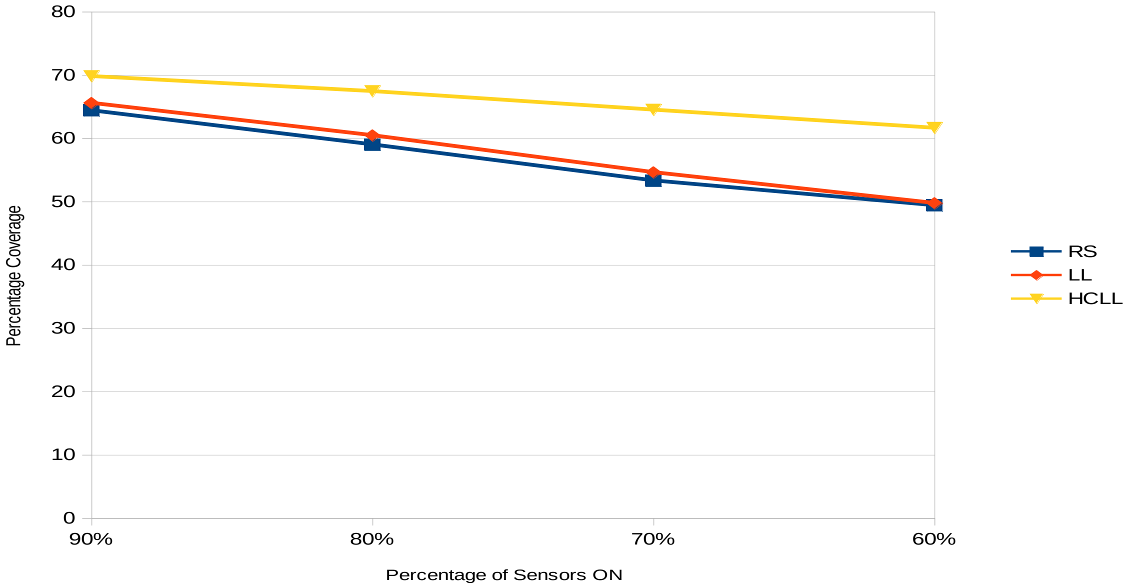


Figure 16. Coverage Percentage Comparison for 75 Sensors

From the above results it is clearly shown that HCLL and LL provides better coverage and increases lifetime of WSN than RS model.

The Empirical results show that the models are consistent in their performance and that network lifetime can be extended using the methodologies.

5. CONCLUSION

In this paper, we devised two models HCLL and LL using an Artificial Bee Colony (ABC) heuristic to solve a problem of scheduling wireless sensors in a network to extend the useful lifetime of the network. HCLL model calculates fitness using a combination of coverage and remaining battery power while the LL model uses remaining battery power only.

The performance of both the models are compared with random generator model RS which randomly chooses the sensors to be turned ON without considering the remaining battery lifetime and network coverage.

The experimental results show that both HCLL and LL methods can prolong network lifetime while maintaining mandatory threshold coverage when compared to the RS model. Our results also show that HCLL model provides better coverage than LL when the area is not densely populated by sensors.

The application designed to run the models lets the user to enter the input parameters. The procedure scales relatively well, in that the computational time required is reasonable as problem size increases.

In our current work, the sensors are stationary. In future work we are planning to extend the method into problems with mobile sensors and also we plan to apply the ABC algorithm for deployment of sensors.

6. REFERENCES

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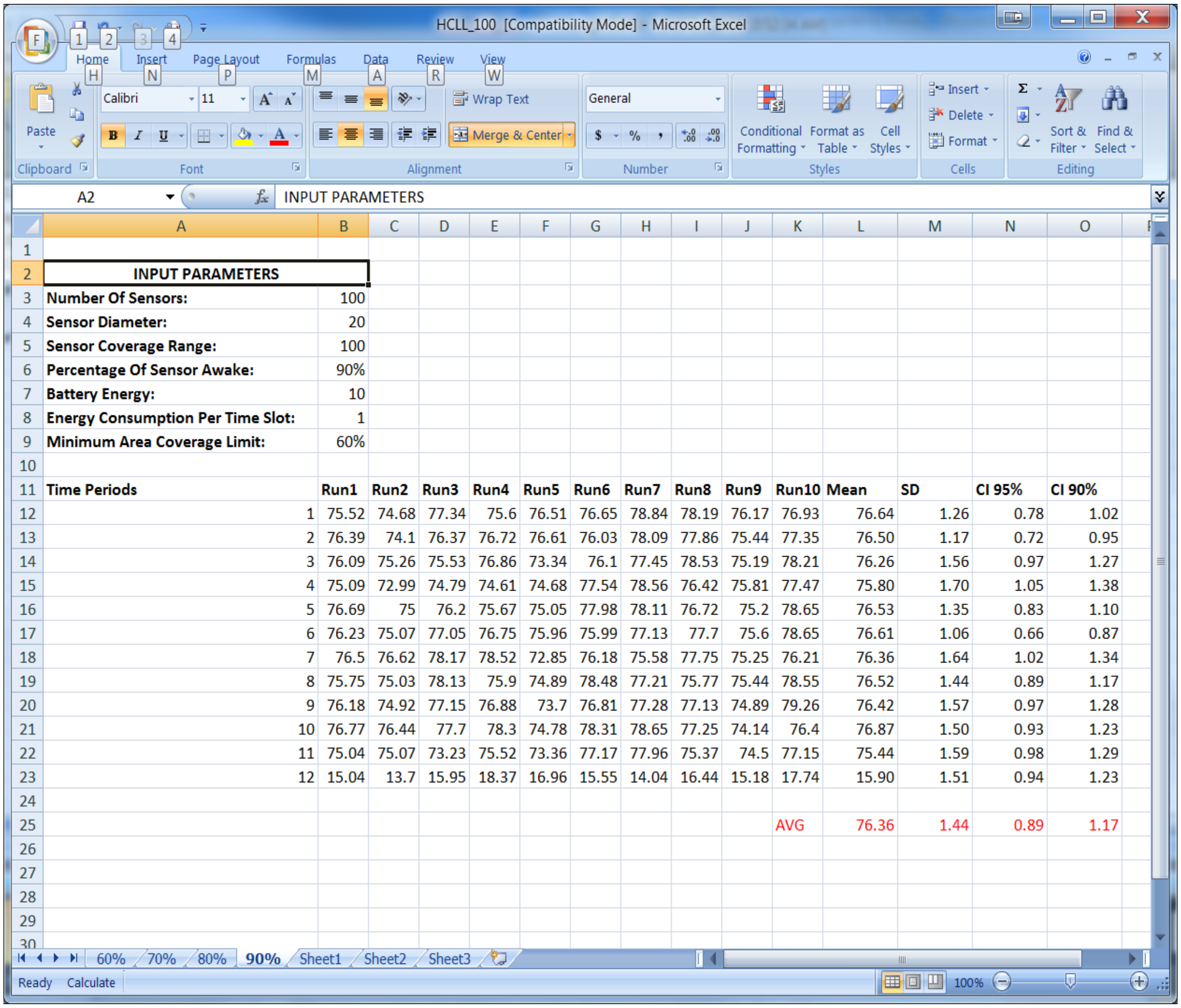
APPENDIX A: EXPERIMENTAL RUNS

In this section we present the data for all of our test runs for our test cases with 100 sensors.

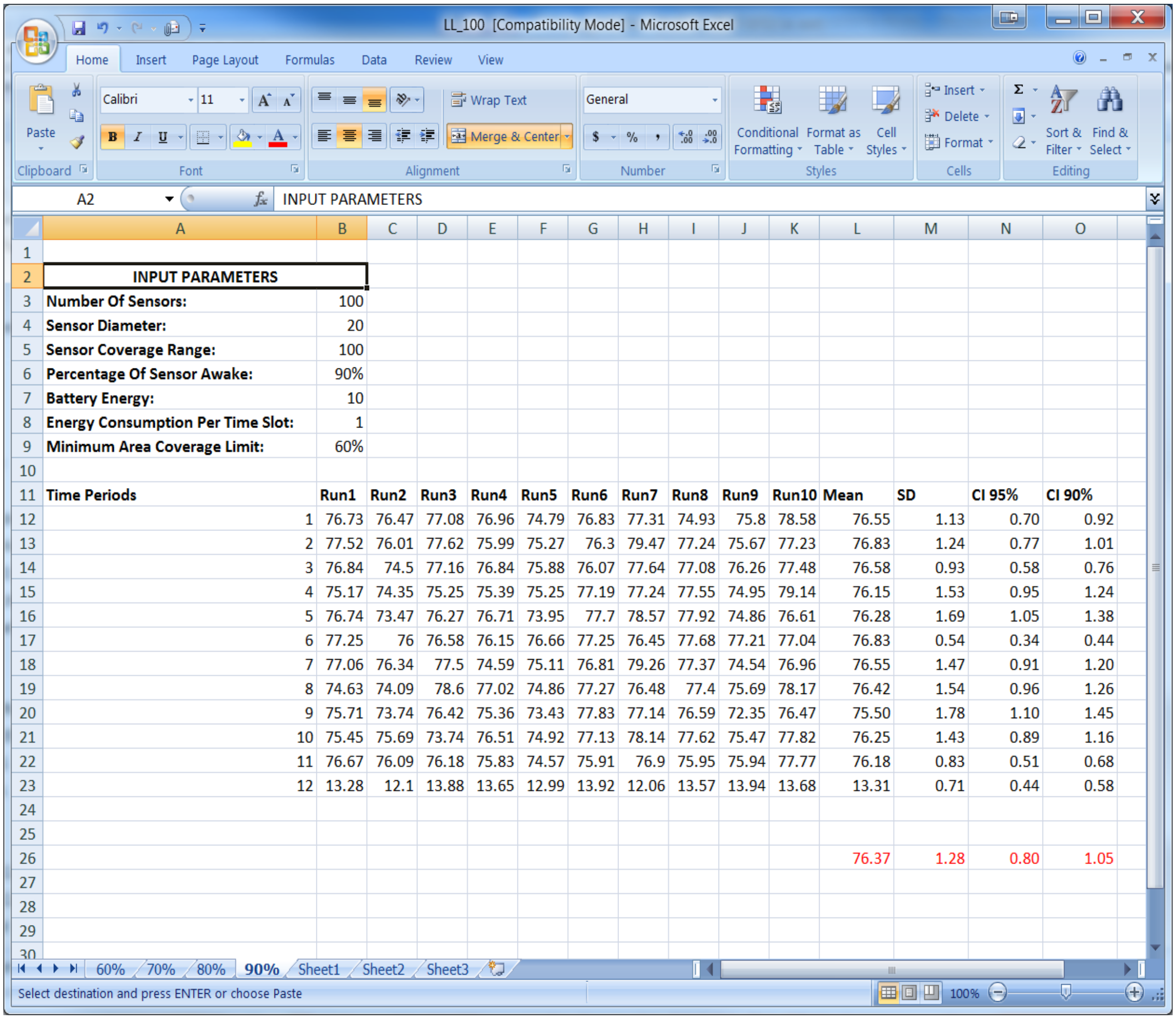


A2: INPUT PARAMETERS

INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	90%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Mean	SD	CI 95%	CI 90%
1	75.52	74.68	77.34	75.6	76.51	76.65	78.84	78.19	76.17	76.93	76.64	1.26	0.78	1.02
2	76.39	74.1	76.37	76.72	76.61	76.03	78.09	77.86	75.44	77.35	76.50	1.17	0.72	0.95
3	76.09	75.26	75.53	76.86	73.34	76.1	77.45	78.53	75.19	78.21	76.26	1.56	0.97	1.27
4	75.09	72.99	74.79	74.61	74.68	77.54	78.56	76.42	75.81	77.47	75.80	1.70	1.05	1.38
5	76.69	75	76.2	75.67	75.05	77.98	78.11	76.72	75.2	78.65	76.53	1.35	0.83	1.10
6	76.23	75.07	77.05	76.75	75.96	75.99	77.13	77.7	75.6	78.65	76.61	1.06	0.66	0.87
7	76.5	76.62	78.17	78.52	72.85	76.18	75.58	77.75	75.25	76.21	76.36	1.64	1.02	1.34
8	75.75	75.03	78.13	75.9	74.89	78.48	77.21	75.77	75.44	78.55	76.52	1.44	0.89	1.17
9	76.18	74.92	77.15	76.88	73.7	76.81	77.28	77.13	74.89	79.26	76.42	1.57	0.97	1.28
10	76.77	76.44	77.7	78.3	74.78	78.31	78.65	77.25	74.14	76.4	76.87	1.50	0.93	1.23
11	75.04	75.07	73.23	75.52	73.36	77.17	77.96	75.37	74.5	77.15	75.44	1.59	0.98	1.29
12	15.04	13.7	15.95	18.37	16.96	15.55	14.04	16.44	15.18	17.74	15.90	1.51	0.94	1.23
										AVG	76.36	1.44	0.89	1.17

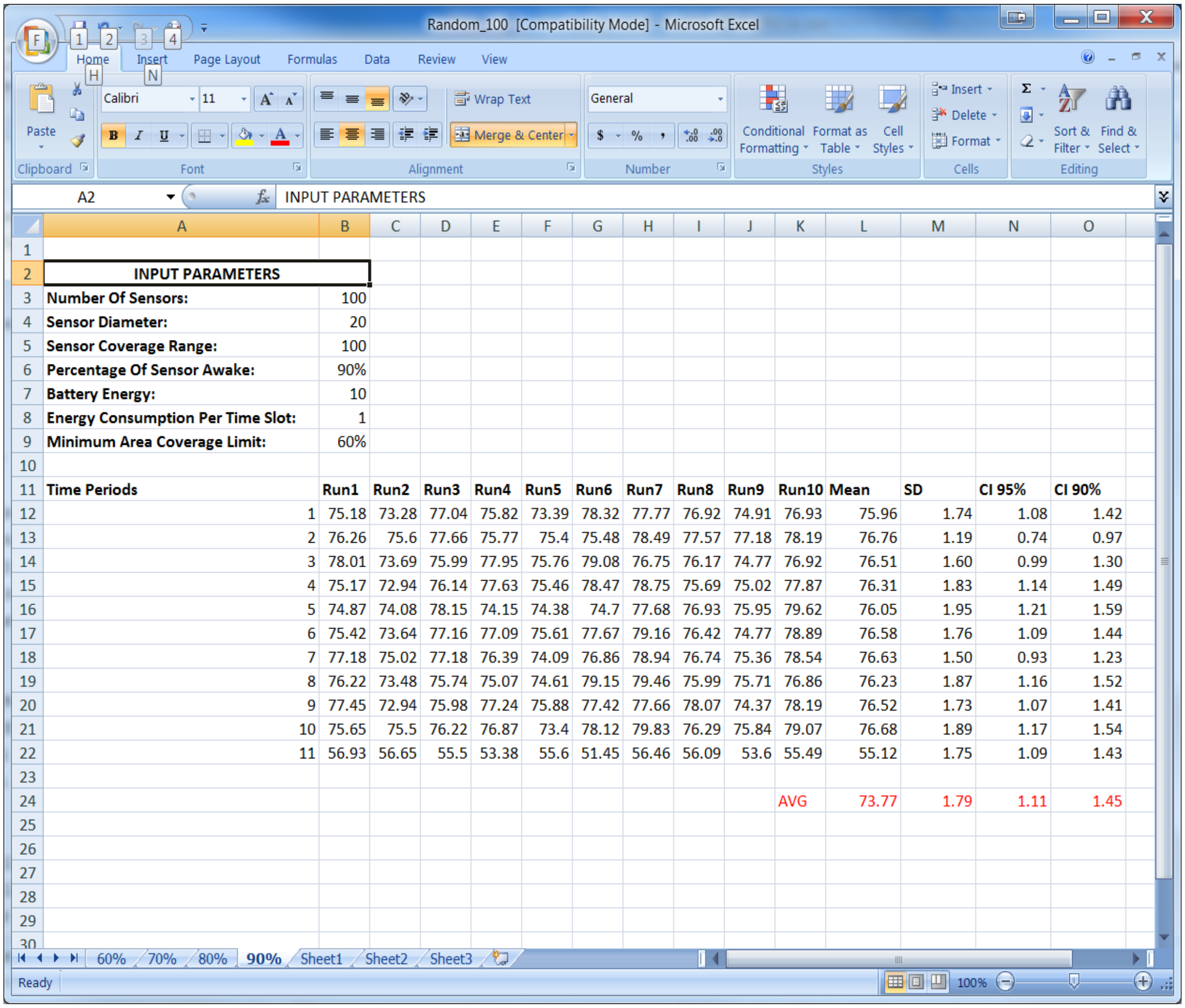
Figure A1. Output File for HCLL When 90% Sensors ON



INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	90%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Mean	SD	CI 95%	CI 90%
1	76.73	76.47	77.08	76.96	74.79	76.83	77.31	74.93	75.8	78.58	76.55	1.13	0.70	0.92
2	77.52	76.01	77.62	75.99	75.27	76.3	79.47	77.24	75.67	77.23	76.83	1.24	0.77	1.01
3	76.84	74.5	77.16	76.84	75.88	76.07	77.64	77.08	76.26	77.48	76.58	0.93	0.58	0.76
4	75.17	74.35	75.25	75.39	75.25	77.19	77.24	77.55	74.95	79.14	76.15	1.53	0.95	1.24
5	76.74	73.47	76.27	76.71	73.95	77.7	78.57	77.92	74.86	76.61	76.28	1.69	1.05	1.38
6	77.25	76	76.58	76.15	76.66	77.25	76.45	77.68	77.21	77.04	76.83	0.54	0.34	0.44
7	77.06	76.34	77.5	74.59	75.11	76.81	79.26	77.37	74.54	76.96	76.55	1.47	0.91	1.20
8	74.63	74.09	78.6	77.02	74.86	77.27	76.48	77.4	75.69	78.17	76.42	1.54	0.96	1.26
9	75.71	73.74	76.42	75.36	73.43	77.83	77.14	76.59	72.35	76.47	75.50	1.78	1.10	1.45
10	75.45	75.69	73.74	76.51	74.92	77.13	78.14	77.62	75.47	77.82	76.25	1.43	0.89	1.16
11	76.67	76.09	76.18	75.83	74.57	75.91	76.9	75.95	75.94	77.77	76.18	0.83	0.51	0.68
12	13.28	12.1	13.88	13.65	12.99	13.92	12.06	13.57	13.94	13.68	13.31	0.71	0.44	0.58
											76.37	1.28	0.80	1.05

Figure A2. Output File for LL When 90% Sensors ON

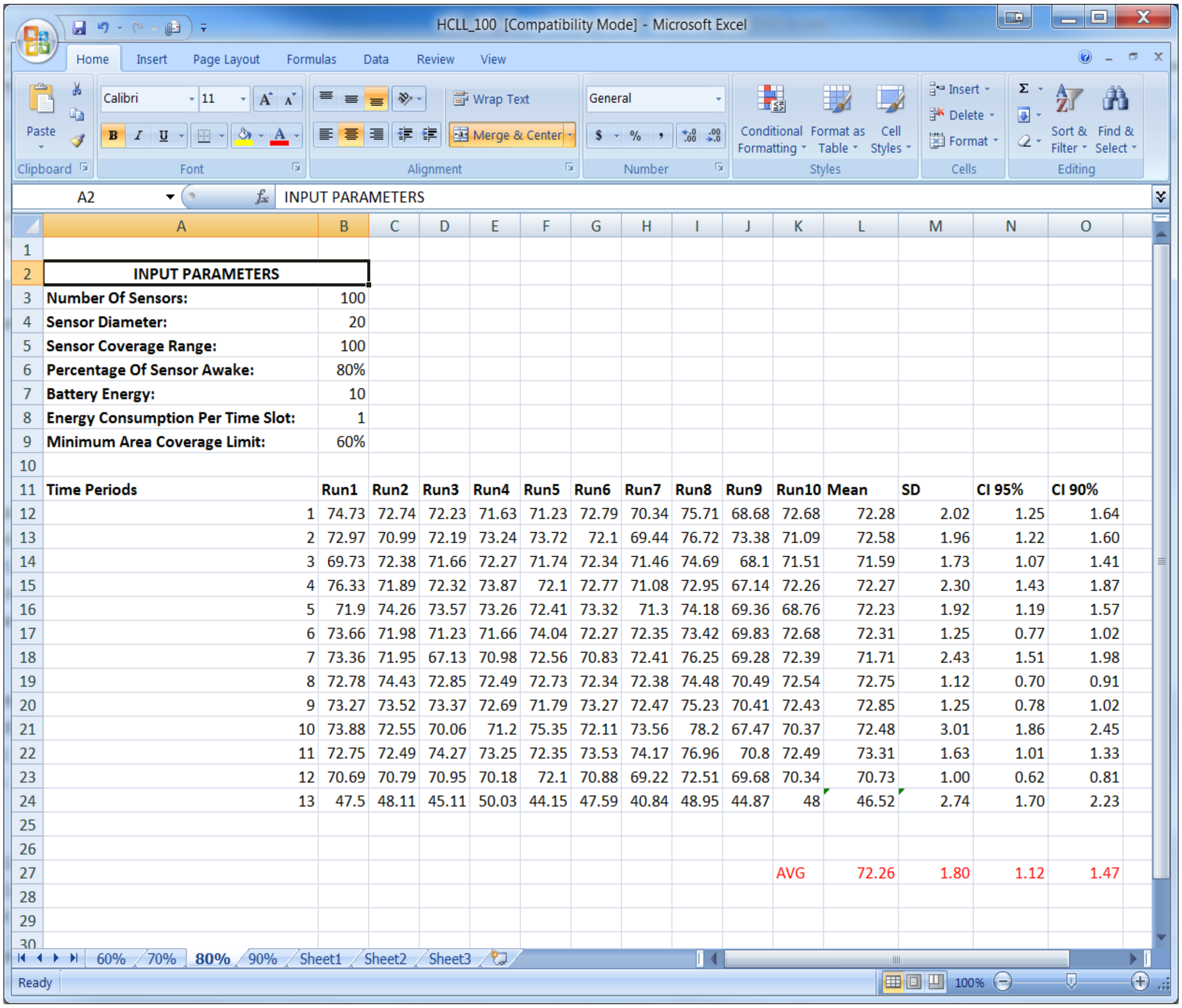


INPUT PARAMETERS

Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	90%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	75.18	73.28	77.04	75.82	73.39	78.32	77.77	76.92	74.91	76.93	75.96	1.74	1.08	1.42
2	76.26	75.6	77.66	75.77	75.4	75.48	78.49	77.57	77.18	78.19	76.76	1.19	0.74	0.97
3	78.01	73.69	75.99	77.95	75.76	79.08	76.75	76.17	74.77	76.92	76.51	1.60	0.99	1.30
4	75.17	72.94	76.14	77.63	75.46	78.47	78.75	75.69	75.02	77.87	76.31	1.83	1.14	1.49
5	74.87	74.08	78.15	74.15	74.38	74.7	77.68	76.93	75.95	79.62	76.05	1.95	1.21	1.59
6	75.42	73.64	77.16	77.09	75.61	77.67	79.16	76.42	74.77	78.89	76.58	1.76	1.09	1.44
7	77.18	75.02	77.18	76.39	74.09	76.86	78.94	76.74	75.36	78.54	76.63	1.50	0.93	1.23
8	76.22	73.48	75.74	75.07	74.61	79.15	79.46	75.99	75.71	76.86	76.23	1.87	1.16	1.52
9	77.45	72.94	75.98	77.24	75.88	77.42	77.66	78.07	74.37	78.19	76.52	1.73	1.07	1.41
10	75.65	75.5	76.22	76.87	73.4	78.12	79.83	76.29	75.84	79.07	76.68	1.89	1.17	1.54
11	56.93	56.65	55.5	53.38	55.6	51.45	56.46	56.09	53.6	55.49	55.12	1.75	1.09	1.43
										AVG	73.77	1.79	1.11	1.45

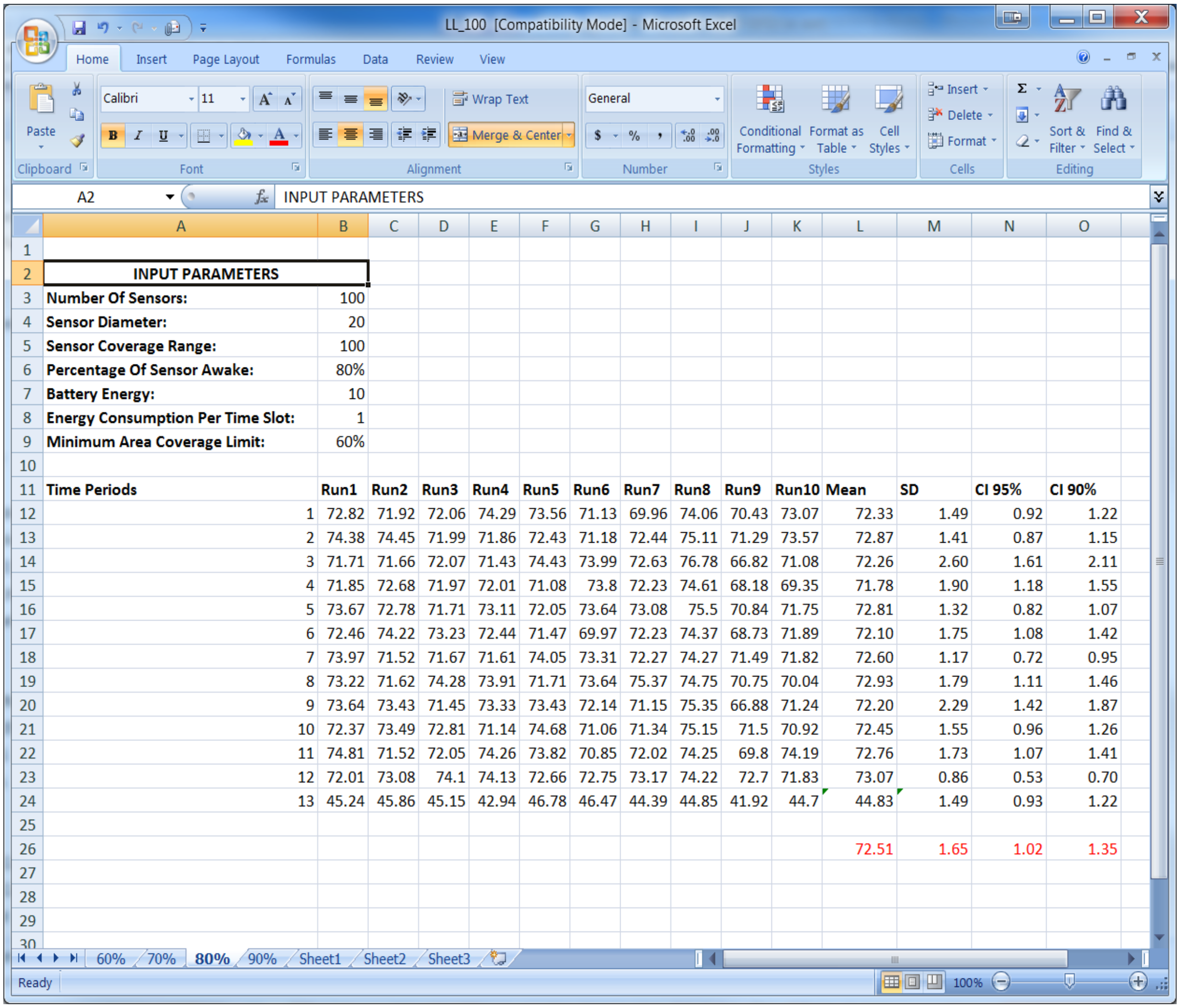
Figure A3. Output File for RS When 90% Sensors ON



INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	80%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Mean	SD	CI 95%	CI 90%
1	74.73	72.74	72.23	71.63	71.23	72.79	70.34	75.71	68.68	72.68	72.28	2.02	1.25	1.64
2	72.97	70.99	72.19	73.24	73.72	72.1	69.44	76.72	73.38	71.09	72.58	1.96	1.22	1.60
3	69.73	72.38	71.66	72.27	71.74	72.34	71.46	74.69	68.1	71.51	71.59	1.73	1.07	1.41
4	76.33	71.89	72.32	73.87	72.1	72.77	71.08	72.95	67.14	72.26	72.27	2.30	1.43	1.87
5	71.9	74.26	73.57	73.26	72.41	73.32	71.3	74.18	69.36	68.76	72.23	1.92	1.19	1.57
6	73.66	71.98	71.23	71.66	74.04	72.27	72.35	73.42	69.83	72.68	72.31	1.25	0.77	1.02
7	73.36	71.95	67.13	70.98	72.56	70.83	72.41	76.25	69.28	72.39	71.71	2.43	1.51	1.98
8	72.78	74.43	72.85	72.49	72.73	72.34	72.38	74.48	70.49	72.54	72.75	1.12	0.70	0.91
9	73.27	73.52	73.37	72.69	71.79	73.27	72.47	75.23	70.41	72.43	72.85	1.25	0.78	1.02
10	73.88	72.55	70.06	71.2	75.35	72.11	73.56	78.2	67.47	70.37	72.48	3.01	1.86	2.45
11	72.75	72.49	74.27	73.25	72.35	73.53	74.17	76.96	70.8	72.49	73.31	1.63	1.01	1.33
12	70.69	70.79	70.95	70.18	72.1	70.88	69.22	72.51	69.68	70.34	70.73	1.00	0.62	0.81
13	47.5	48.11	45.11	50.03	44.15	47.59	40.84	48.95	44.87	48	46.52	2.74	1.70	2.23
										AVG	72.26	1.80	1.12	1.47

Figure A4. Output File for HCLL When 80% Sensors ON

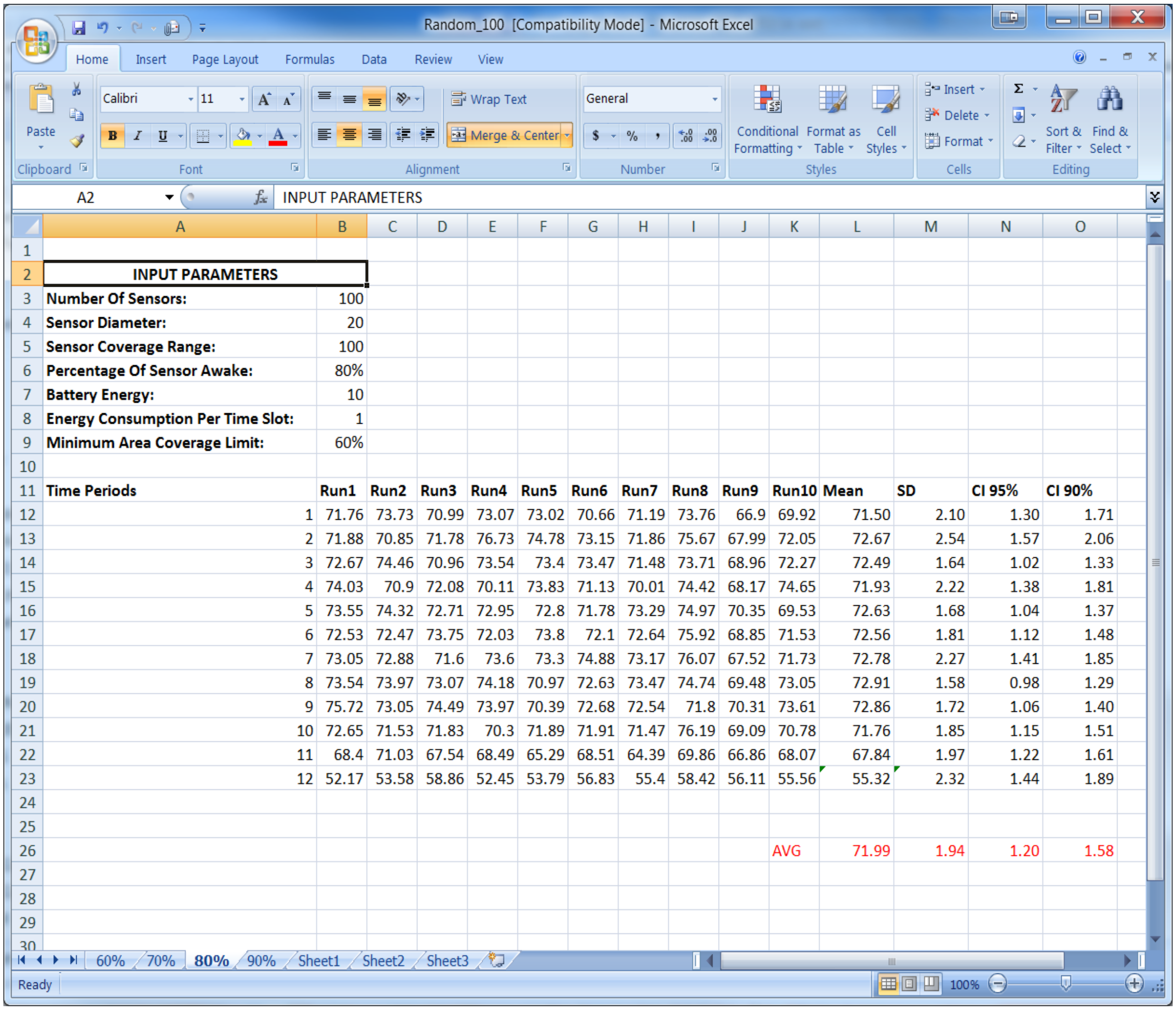


INPUT PARAMETERS

INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	80%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	72.82	71.92	72.06	74.29	73.56	71.13	69.96	74.06	70.43	73.07	72.33	1.49	0.92	1.22
2	74.38	74.45	71.99	71.86	72.43	71.18	72.44	75.11	71.29	73.57	72.87	1.41	0.87	1.15
3	71.71	71.66	72.07	71.43	74.43	73.99	72.63	76.78	66.82	71.08	72.26	2.60	1.61	2.11
4	71.85	72.68	71.97	72.01	71.08	73.8	72.23	74.61	68.18	69.35	71.78	1.90	1.18	1.55
5	73.67	72.78	71.71	73.11	72.05	73.64	73.08	75.5	70.84	71.75	72.81	1.32	0.82	1.07
6	72.46	74.22	73.23	72.44	71.47	69.97	72.23	74.37	68.73	71.89	72.10	1.75	1.08	1.42
7	73.97	71.52	71.67	71.61	74.05	73.31	72.27	74.27	71.49	71.82	72.60	1.17	0.72	0.95
8	73.22	71.62	74.28	73.91	71.71	73.64	75.37	74.75	70.75	70.04	72.93	1.79	1.11	1.46
9	73.64	73.43	71.45	73.33	73.43	72.14	71.15	75.35	66.88	71.24	72.20	2.29	1.42	1.87
10	72.37	73.49	72.81	71.14	74.68	71.06	71.34	75.15	71.5	70.92	72.45	1.55	0.96	1.26
11	74.81	71.52	72.05	74.26	73.82	70.85	72.02	74.25	69.8	74.19	72.76	1.73	1.07	1.41
12	72.01	73.08	74.1	74.13	72.66	72.75	73.17	74.22	72.7	71.83	73.07	0.86	0.53	0.70
13	45.24	45.86	45.15	42.94	46.78	46.47	44.39	44.85	41.92	44.7	44.83	1.49	0.93	1.22
											72.51	1.65	1.02	1.35

Figure A5. Output File for LL When 80% Sensors ON

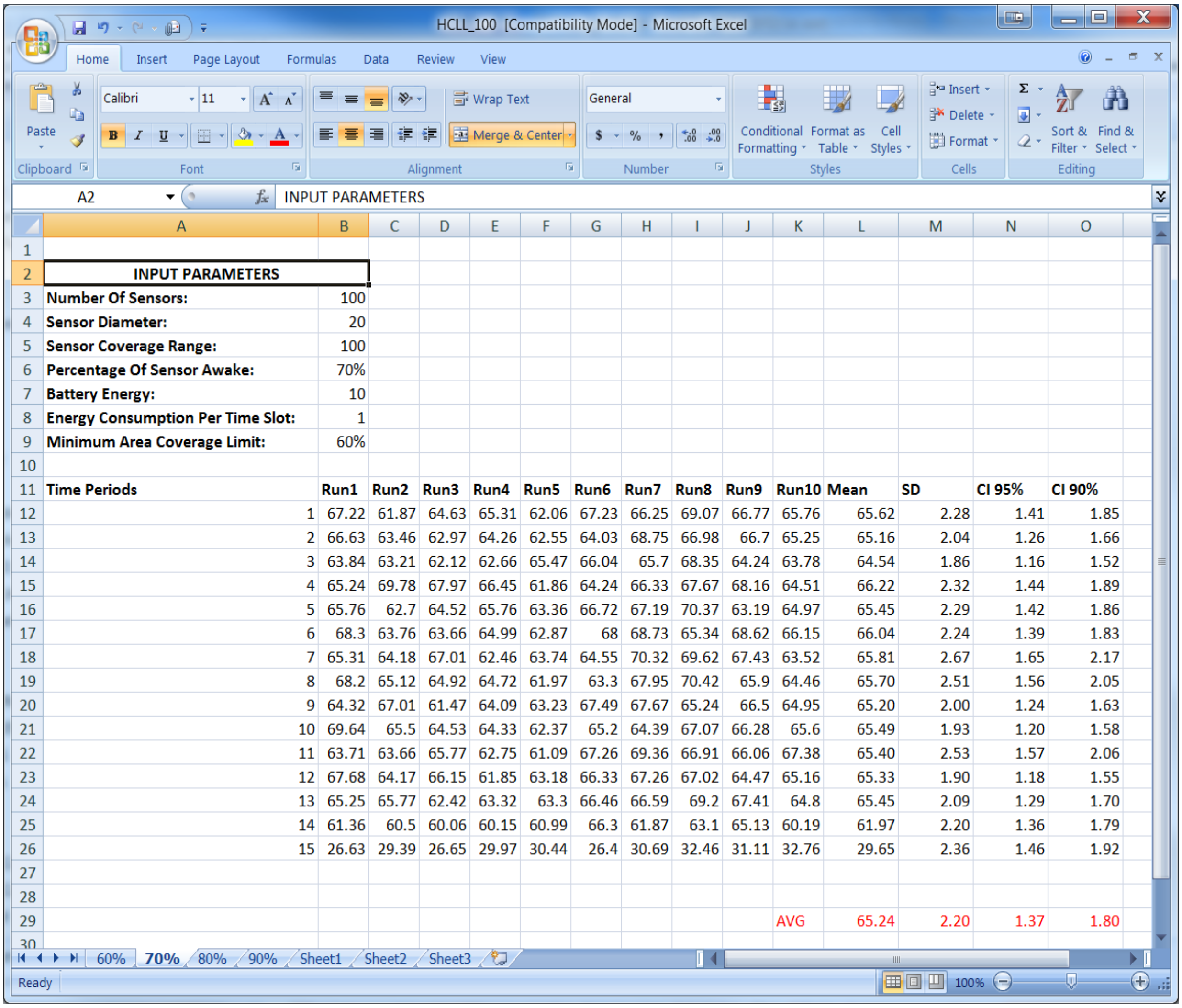


INPUT PARAMETERS

INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	80%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	71.76	73.73	70.99	73.07	73.02	70.66	71.19	73.76	66.9	69.92	71.50	2.10	1.30	1.71
2	71.88	70.85	71.78	76.73	74.78	73.15	71.86	75.67	67.99	72.05	72.67	2.54	1.57	2.06
3	72.67	74.46	70.96	73.54	73.4	73.47	71.48	73.71	68.96	72.27	72.49	1.64	1.02	1.33
4	74.03	70.9	72.08	70.11	73.83	71.13	70.01	74.42	68.17	74.65	71.93	2.22	1.38	1.81
5	73.55	74.32	72.71	72.95	72.8	71.78	73.29	74.97	70.35	69.53	72.63	1.68	1.04	1.37
6	72.53	72.47	73.75	72.03	73.8	72.1	72.64	75.92	68.85	71.53	72.56	1.81	1.12	1.48
7	73.05	72.88	71.6	73.6	73.3	74.88	73.17	76.07	67.52	71.73	72.78	2.27	1.41	1.85
8	73.54	73.97	73.07	74.18	70.97	72.63	73.47	74.74	69.48	73.05	72.91	1.58	0.98	1.29
9	75.72	73.05	74.49	73.97	70.39	72.68	72.54	71.8	70.31	73.61	72.86	1.72	1.06	1.40
10	72.65	71.53	71.83	70.3	71.89	71.91	71.47	76.19	69.09	70.78	71.76	1.85	1.15	1.51
11	68.4	71.03	67.54	68.49	65.29	68.51	64.39	69.86	66.86	68.07	67.84	1.97	1.22	1.61
12	52.17	53.58	58.86	52.45	53.79	56.83	55.4	58.42	56.11	55.56	55.32	2.32	1.44	1.89
										AVG	71.99	1.94	1.20	1.58

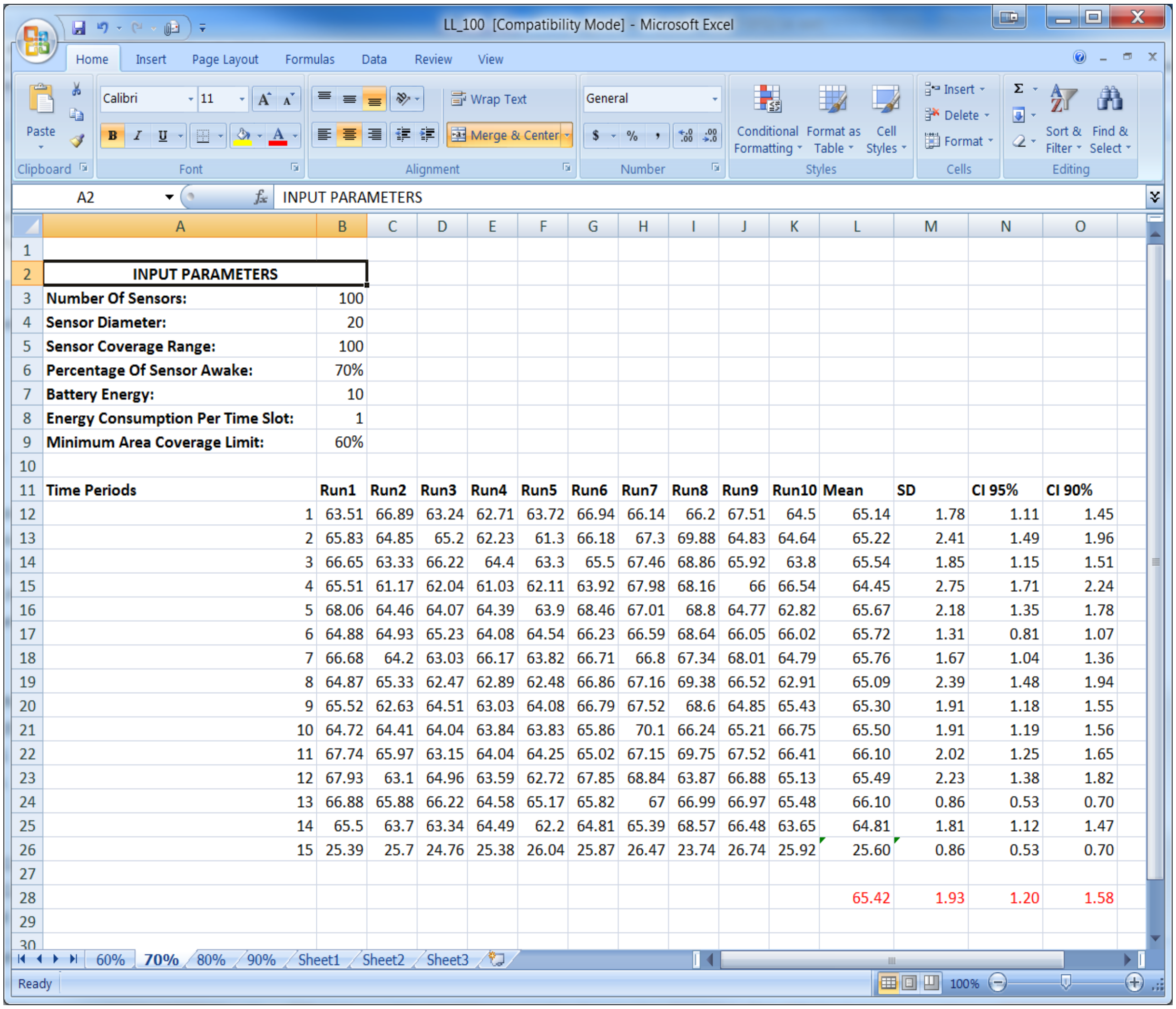
Figure A6. Output File for RS When 80% Sensors ON



INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	70%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Mean	SD	CI 95%	CI 90%
1	67.22	61.87	64.63	65.31	62.06	67.23	66.25	69.07	66.77	65.76	65.62	2.28	1.41	1.85
2	66.63	63.46	62.97	64.26	62.55	64.03	68.75	66.98	66.7	65.25	65.16	2.04	1.26	1.66
3	63.84	63.21	62.12	62.66	65.47	66.04	65.7	68.35	64.24	63.78	64.54	1.86	1.16	1.52
4	65.24	69.78	67.97	66.45	61.86	64.24	66.33	67.67	68.16	64.51	66.22	2.32	1.44	1.89
5	65.76	62.7	64.52	65.76	63.36	66.72	67.19	70.37	63.19	64.97	65.45	2.29	1.42	1.86
6	68.3	63.76	63.66	64.99	62.87	68	68.73	65.34	68.62	66.15	66.04	2.24	1.39	1.83
7	65.31	64.18	67.01	62.46	63.74	64.55	70.32	69.62	67.43	63.52	65.81	2.67	1.65	2.17
8	68.2	65.12	64.92	64.72	61.97	63.3	67.95	70.42	65.9	64.46	65.70	2.51	1.56	2.05
9	64.32	67.01	61.47	64.09	63.23	67.49	67.67	65.24	66.5	64.95	65.20	2.00	1.24	1.63
10	69.64	65.5	64.53	64.33	62.37	65.2	64.39	67.07	66.28	65.6	65.49	1.93	1.20	1.58
11	63.71	63.66	65.77	62.75	61.09	67.26	69.36	66.91	66.06	67.38	65.40	2.53	1.57	2.06
12	67.68	64.17	66.15	61.85	63.18	66.33	67.26	67.02	64.47	65.16	65.33	1.90	1.18	1.55
13	65.25	65.77	62.42	63.32	63.3	66.46	66.59	69.2	67.41	64.8	65.45	2.09	1.29	1.70
14	61.36	60.5	60.06	60.15	60.99	66.3	61.87	63.1	65.13	60.19	61.97	2.20	1.36	1.79
15	26.63	29.39	26.65	29.97	30.44	26.4	30.69	32.46	31.11	32.76	29.65	2.36	1.46	1.92
										AVG	65.24	2.20	1.37	1.80

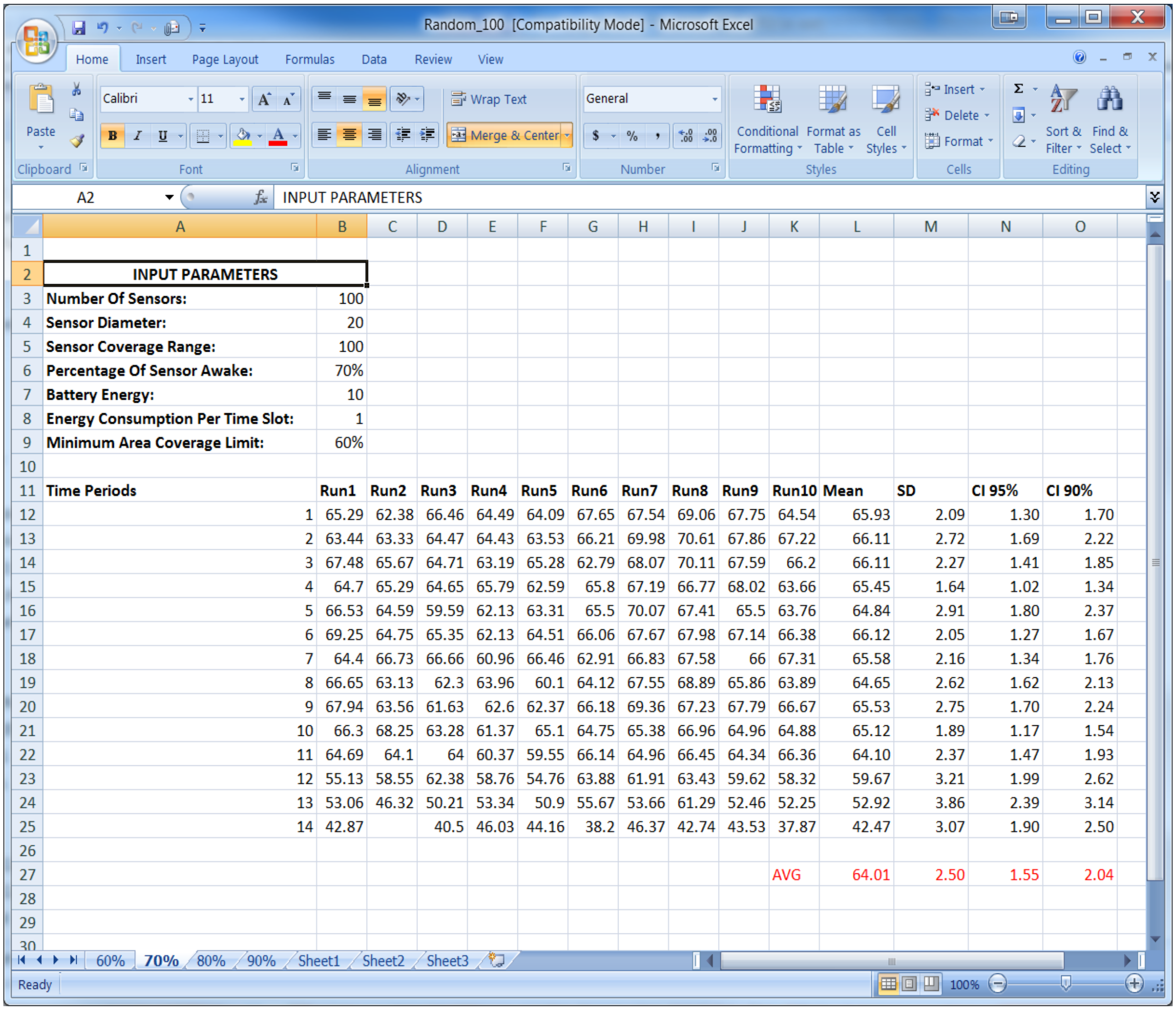
Figure A7. Output File for HCLL When 70% Sensors ON



INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	70%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Mean	SD	CI 95%	CI 90%
1	63.51	66.89	63.24	62.71	63.72	66.94	66.14	66.2	67.51	64.5	65.14	1.78	1.11	1.45
2	65.83	64.85	65.2	62.23	61.3	66.18	67.3	69.88	64.83	64.64	65.22	2.41	1.49	1.96
3	66.65	63.33	66.22	64.4	63.3	65.5	67.46	68.86	65.92	63.8	65.54	1.85	1.15	1.51
4	65.51	61.17	62.04	61.03	62.11	63.92	67.98	68.16	66	66.54	64.45	2.75	1.71	2.24
5	68.06	64.46	64.07	64.39	63.9	68.46	67.01	68.8	64.77	62.82	65.67	2.18	1.35	1.78
6	64.88	64.93	65.23	64.08	64.54	66.23	66.59	68.64	66.05	66.02	65.72	1.31	0.81	1.07
7	66.68	64.2	63.03	66.17	63.82	66.71	66.8	67.34	68.01	64.79	65.76	1.67	1.04	1.36
8	64.87	65.33	62.47	62.89	62.48	66.86	67.16	69.38	66.52	62.91	65.09	2.39	1.48	1.94
9	65.52	62.63	64.51	63.03	64.08	66.79	67.52	68.6	64.85	65.43	65.30	1.91	1.18	1.55
10	64.72	64.41	64.04	63.84	63.83	65.86	70.1	66.24	65.21	66.75	65.50	1.91	1.19	1.56
11	67.74	65.97	63.15	64.04	64.25	65.02	67.15	69.75	67.52	66.41	66.10	2.02	1.25	1.65
12	67.93	63.1	64.96	63.59	62.72	67.85	68.84	63.87	66.88	65.13	65.49	2.23	1.38	1.82
13	66.88	65.88	66.22	64.58	65.17	65.82	67	66.99	66.97	65.48	66.10	0.86	0.53	0.70
14	65.5	63.7	63.34	64.49	62.2	64.81	65.39	68.57	66.48	63.65	64.81	1.81	1.12	1.47
15	25.39	25.7	24.76	25.38	26.04	25.87	26.47	23.74	26.74	25.92	25.60	0.86	0.53	0.70
											65.42	1.93	1.20	1.58

Figure A8. Output File for LL When 70% Sensors ON

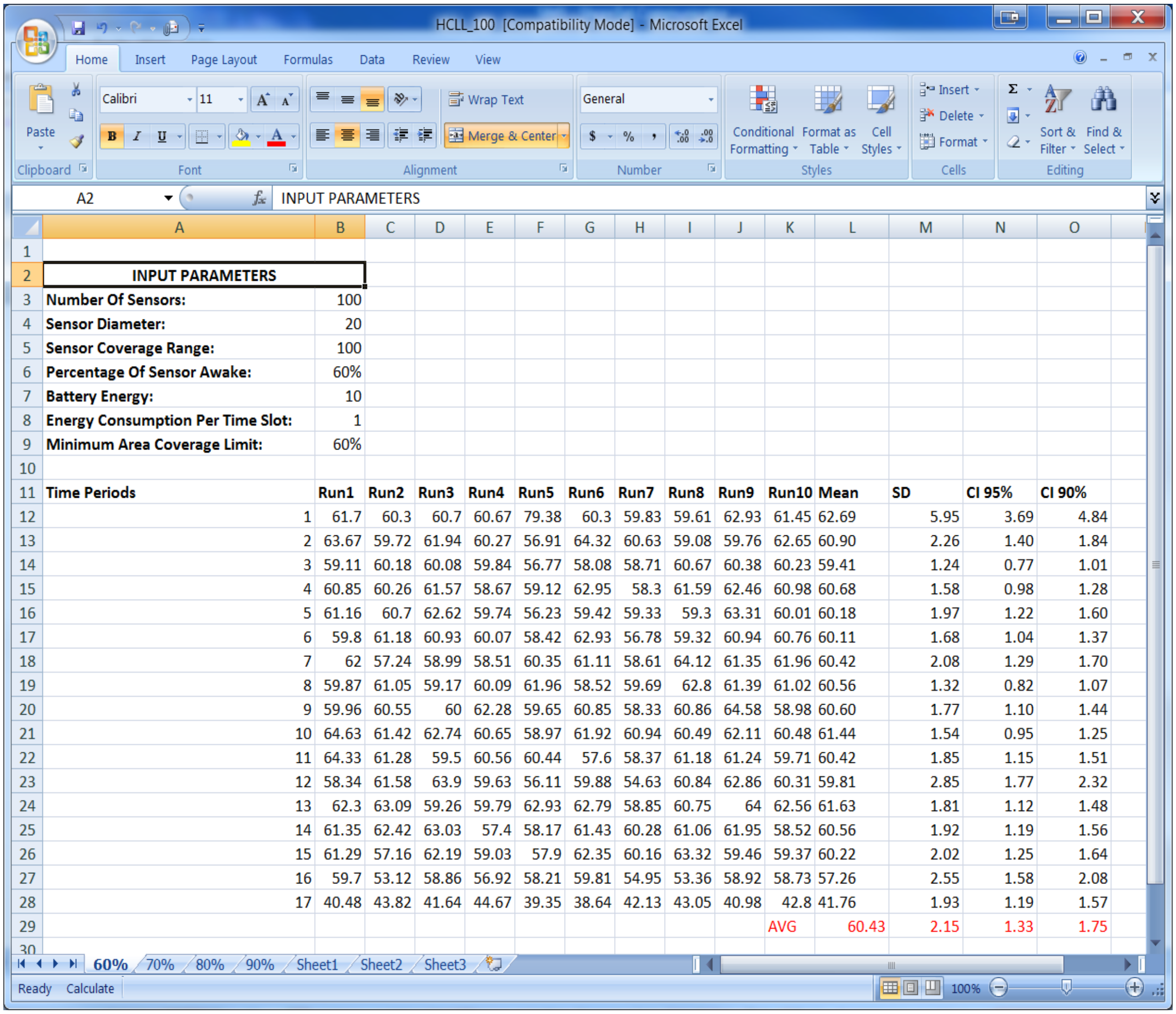


INPUT PARAMETERS

Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	70%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	65.29	62.38	66.46	64.49	64.09	67.65	67.54	69.06	67.75	64.54	65.93	2.09	1.30	1.70
2	63.44	63.33	64.47	64.43	63.53	66.21	69.98	70.61	67.86	67.22	66.11	2.72	1.69	2.22
3	67.48	65.67	64.71	63.19	65.28	62.79	68.07	70.11	67.59	66.2	66.11	2.27	1.41	1.85
4	64.7	65.29	64.65	65.79	62.59	65.8	67.19	66.77	68.02	63.66	65.45	1.64	1.02	1.34
5	66.53	64.59	59.59	62.13	63.31	65.5	70.07	67.41	65.5	63.76	64.84	2.91	1.80	2.37
6	69.25	64.75	65.35	62.13	64.51	66.06	67.67	67.98	67.14	66.38	66.12	2.05	1.27	1.67
7	64.4	66.73	66.66	60.96	66.46	62.91	66.83	67.58	66	67.31	65.58	2.16	1.34	1.76
8	66.65	63.13	62.3	63.96	60.1	64.12	67.55	68.89	65.86	63.89	64.65	2.62	1.62	2.13
9	67.94	63.56	61.63	62.6	62.37	66.18	69.36	67.23	67.79	66.67	65.53	2.75	1.70	2.24
10	66.3	68.25	63.28	61.37	65.1	64.75	65.38	66.96	64.96	64.88	65.12	1.89	1.17	1.54
11	64.69	64.1	64	60.37	59.55	66.14	64.96	66.45	64.34	66.36	64.10	2.37	1.47	1.93
12	55.13	58.55	62.38	58.76	54.76	63.88	61.91	63.43	59.62	58.32	59.67	3.21	1.99	2.62
13	53.06	46.32	50.21	53.34	50.9	55.67	53.66	61.29	52.46	52.25	52.92	3.86	2.39	3.14
14	42.87		40.5	46.03	44.16	38.2	46.37	42.74	43.53	37.87	42.47	3.07	1.90	2.50
										AVG	64.01	2.50	1.55	2.04

Figure A9. Output File for RS When 70% Sensors ON

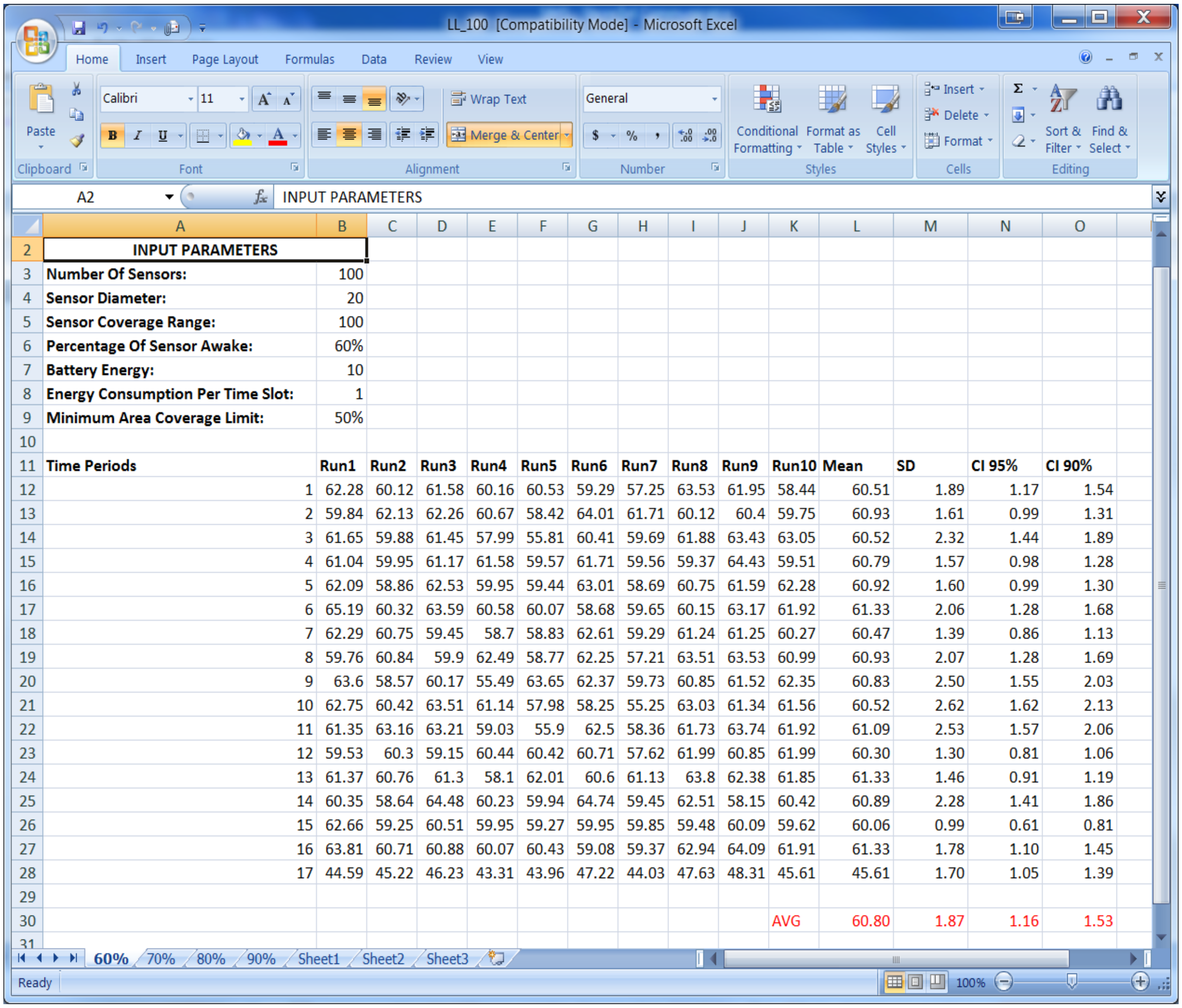


A2 INPUT PARAMETERS

INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	60%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	60%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	61.7	60.3	60.7	60.67	79.38	60.3	59.83	59.61	62.93	61.45	62.69	5.95	3.69	4.84
2	63.67	59.72	61.94	60.27	56.91	64.32	60.63	59.08	59.76	62.65	60.90	2.26	1.40	1.84
3	59.11	60.18	60.08	59.84	56.77	58.08	58.71	60.67	60.38	60.23	59.41	1.24	0.77	1.01
4	60.85	60.26	61.57	58.67	59.12	62.95	58.3	61.59	62.46	60.98	60.68	1.58	0.98	1.28
5	61.16	60.7	62.62	59.74	56.23	59.42	59.33	59.3	63.31	60.01	60.18	1.97	1.22	1.60
6	59.8	61.18	60.93	60.07	58.42	62.93	56.78	59.32	60.94	60.76	60.11	1.68	1.04	1.37
7	62	57.24	58.99	58.51	60.35	61.11	58.61	64.12	61.35	61.96	60.42	2.08	1.29	1.70
8	59.87	61.05	59.17	60.09	61.96	58.52	59.69	62.8	61.39	61.02	60.56	1.32	0.82	1.07
9	59.96	60.55	60	62.28	59.65	60.85	58.33	60.86	64.58	58.98	60.60	1.77	1.10	1.44
10	64.63	61.42	62.74	60.65	58.97	61.92	60.94	60.49	62.11	60.48	61.44	1.54	0.95	1.25
11	64.33	61.28	59.5	60.56	60.44	57.6	58.37	61.18	61.24	59.71	60.42	1.85	1.15	1.51
12	58.34	61.58	63.9	59.63	56.11	59.88	54.63	60.84	62.86	60.31	59.81	2.85	1.77	2.32
13	62.3	63.09	59.26	59.79	62.93	62.79	58.85	60.75	64	62.56	61.63	1.81	1.12	1.48
14	61.35	62.42	63.03	57.4	58.17	61.43	60.28	61.06	61.95	58.52	60.56	1.92	1.19	1.56
15	61.29	57.16	62.19	59.03	57.9	62.35	60.16	63.32	59.46	59.37	60.22	2.02	1.25	1.64
16	59.7	53.12	58.86	56.92	58.21	59.81	54.95	53.36	58.92	58.73	57.26	2.55	1.58	2.08
17	40.48	43.82	41.64	44.67	39.35	38.64	42.13	43.05	40.98	42.8	41.76	1.93	1.19	1.57
										AVG	60.43	2.15	1.33	1.75

Figure A10. Output File for HCLL When 60% Sensors ON

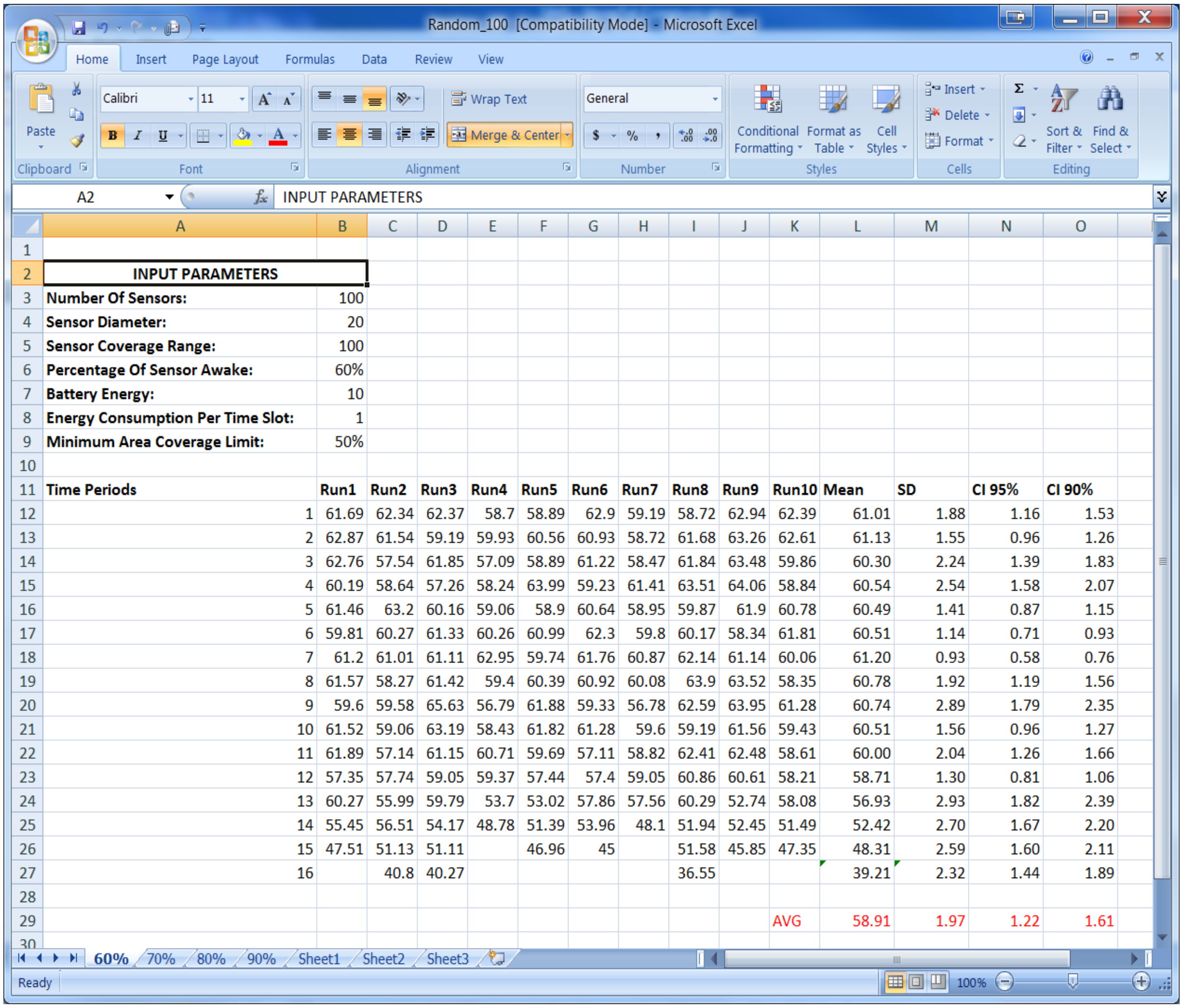


A2 INPUT PARAMETERS

INPUT PARAMETERS	
Number Of Sensors:	100
Sensor Diameter:	20
Sensor Coverage Range:	100
Percentage Of Sensor Awake:	60%
Battery Energy:	10
Energy Consumption Per Time Slot:	1
Minimum Area Coverage Limit:	50%

Time Periods	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
1	62.28	60.12	61.58	60.16	60.53	59.29	57.25	63.53	61.95	58.44	60.51	1.89	1.17	1.54
2	59.84	62.13	62.26	60.67	58.42	64.01	61.71	60.12	60.4	59.75	60.93	1.61	0.99	1.31
3	61.65	59.88	61.45	57.99	55.81	60.41	59.69	61.88	63.43	63.05	60.52	2.32	1.44	1.89
4	61.04	59.95	61.17	61.58	59.57	61.71	59.56	59.37	64.43	59.51	60.79	1.57	0.98	1.28
5	62.09	58.86	62.53	59.95	59.44	63.01	58.69	60.75	61.59	62.28	60.92	1.60	0.99	1.30
6	65.19	60.32	63.59	60.58	60.07	58.68	59.65	60.15	63.17	61.92	61.33	2.06	1.28	1.68
7	62.29	60.75	59.45	58.7	58.83	62.61	59.29	61.24	61.25	60.27	60.47	1.39	0.86	1.13
8	59.76	60.84	59.9	62.49	58.77	62.25	57.21	63.51	63.53	60.99	60.93	2.07	1.28	1.69
9	63.6	58.57	60.17	55.49	63.65	62.37	59.73	60.85	61.52	62.35	60.83	2.50	1.55	2.03
10	62.75	60.42	63.51	61.14	57.98	58.25	55.25	63.03	61.34	61.56	60.52	2.62	1.62	2.13
11	61.35	63.16	63.21	59.03	55.9	62.5	58.36	61.73	63.74	61.92	61.09	2.53	1.57	2.06
12	59.53	60.3	59.15	60.44	60.42	60.71	57.62	61.99	60.85	61.99	60.30	1.30	0.81	1.06
13	61.37	60.76	61.3	58.1	62.01	60.6	61.13	63.8	62.38	61.85	61.33	1.46	0.91	1.19
14	60.35	58.64	64.48	60.23	59.94	64.74	59.45	62.51	58.15	60.42	60.89	2.28	1.41	1.86
15	62.66	59.25	60.51	59.95	59.27	59.95	59.85	59.48	60.09	59.62	60.06	0.99	0.61	0.81
16	63.81	60.71	60.88	60.07	60.43	59.08	59.37	62.94	64.09	61.91	61.33	1.78	1.10	1.45
17	44.59	45.22	46.23	43.31	43.96	47.22	44.03	47.63	48.31	45.61	45.61	1.70	1.05	1.39
										AVG	60.80	1.87	1.16	1.53

Figure A11. Output File for LL When 60% Sensors ON



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2	**INPUT PARAMETERS**														
3	**Number Of Sensors:**	100													
4	**Sensor Diameter:**	20													
5	**Sensor Coverage Range:**	100													
6	**Percentage Of Sensor Awake:**	60%													
7	**Battery Energy:**	10													
8	**Energy Consumption Per Time Slot:**	1													
9	**Minimum Area Coverage Limit:**	50%													
10															
11	**Time Periods**	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**	**Mean**	**SD**	**CI 95%**	**CI 90%**
12	1	61.69	62.34	62.37	58.7	58.89	62.9	59.19	58.72	62.94	62.39	61.01	1.88	1.16	1.53
13	2	62.87	61.54	59.19	59.93	60.56	60.93	58.72	61.68	63.26	62.61	61.13	1.55	0.96	1.26
14	3	62.76	57.54	61.85	57.09	58.89	61.22	58.47	61.84	63.48	59.86	60.30	2.24	1.39	1.83
15	4	60.19	58.64	57.26	58.24	63.99	59.23	61.41	63.51	64.06	58.84	60.54	2.54	1.58	2.07
16	5	61.46	63.2	60.16	59.06	58.9	60.64	58.95	59.87	61.9	60.78	60.49	1.41	0.87	1.15
17	6	59.81	60.27	61.33	60.26	60.99	62.3	59.8	60.17	58.34	61.81	60.51	1.14	0.71	0.93
18	7	61.2	61.01	61.11	62.95	59.74	61.76	60.87	62.14	61.14	60.06	61.20	0.93	0.58	0.76
19	8	61.57	58.27	61.42	59.4	60.39	60.92	60.08	63.9	63.52	58.35	60.78	1.92	1.19	1.56
20	9	59.6	59.58	65.63	56.79	61.88	59.33	56.78	62.59	63.95	61.28	60.74	2.89	1.79	2.35
21	10	61.52	59.06	63.19	58.43	61.82	61.28	59.6	59.19	61.56	59.43	60.51	1.56	0.96	1.27
22	11	61.89	57.14	61.15	60.71	59.69	57.11	58.82	62.41	62.48	58.61	60.00	2.04	1.26	1.66
23	12	57.35	57.74	59.05	59.37	57.44	57.4	59.05	60.86	60.61	58.21	58.71	1.30	0.81	1.06
24	13	60.27	55.99	59.79	53.7	53.02	57.86	57.56	60.29	52.74	58.08	56.93	2.93	1.82	2.39
25	14	55.45	56.51	54.17	48.78	51.39	53.96	48.1	51.94	52.45	51.49	52.42	2.70	1.67	2.20
26	15	47.51	51.13	51.11		46.96	45		51.58	45.85	47.35	48.31	2.59	1.60	2.11
27	16		40.8	40.27					36.55			39.21	2.32	1.44	1.89
28															
29											AVG	58.91	1.97	1.22	1.61
30															

Figure A12. Output File for RS When 60% Sensors ON