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Wireless Sensor Network Coverage Demonstarting Power Savings and Limitations with Minimized Coverage

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ABSTRACT

This paper explores the competing issues of coverage efficiency and power available in wireless sensor networks. Specifically, a shortest distance routing protocol has to be implemented, and total network system lifetimes are determined using a variety of small percentages of the available system nodes. Using a network simulator developed in Java, wireless sensor nodes are simulated, and power consumption algorithms are included in each node that take into consideration all aspects of power consumption in the operation of the node. Simulating different coverage schemes on the same network system, same initial power sources, and routing protocol, an increase of overall system lifetime of 900% is demonstrated, but also that the network lifetime increase does not increase linearly as the percentage of nodes used in the system is decreased.

Keywords: wireless, network, power saving.

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INTRODUCTION

Wireless sensor networks (WSNs) are grouped with the elements that are well equipped with integrated functionalities of communication, sensing and computation [1-3]. These sensors typically operate with small size batteries which have more expensive and very difficult to recharge or replace. Moreover, these sensors can perform some simple functions which may not able to implementing multiple access schemes and sophisticated coding modulation [4]. These sensors are capable to develop a wireless network. They can transfer the data among their neighbors via wireless channels and with other sensors in the network via intermediate sensors, in order to organize their sensing activities. WSNs can be characterized through large number of connected wireless sensors [5]. Recent advances in digital electronics, wireless communication technologies and Micro-Electro-Mechanical Systems (MEMS) have enabled the implementation of large-scale WSNs, where tens of thousands of sensors are distributed over a wide area to detect interesting events and information send it to the sink [6, 7]. Defects may occur in any large-scale of network and centralized control network leads to increase performance evaluation issues and challenging design in such networks. Among them, a peculiar characteristics of wireless sensor network is that the required and desired global system performance can be achieved based on decisions and local information collected from every individual sensor within the network. One basic fundamental global property in wireless sensor network is connectivity; verify that the each sensor can transmit data to any other sensor over multiple hops [8]. It is really a challenging task against maintaining connectivity for all networks owing to the limited transmission range, power supply constraints and some sensors may be down when they run out of energy. Moreover, connectivity may also affect owing to the wireless medium get severe attenuation through environmental or ambient noise and external interference. Thus, the connectivity among the sensor may differ with time. Consequently, the network topologies are unpredictable and varying enormously over time, resulting in arbitrary topologies. The WSNs topology may be described through the scheduling scheme, transmission range and the properties of the wireless medium while network control is shared among the sensors [9]. Accordingly, it is fundamental challenges for wireless sensor network to maintain connectivity in a distributed fashion through topology controlling functions exist in between the network routing layer and the medium access control (MAC). Network lifetime is an essential fundamental global property. It is illustrated as the period from start to the moment of network operation when the beginning sensor in the network runs with out of energy [10-13]. One method for maximizing the network lifetime is to reduce sensors transmission power satisfactorily in order to achieve contact with their farthest selected neighbor. Not only reduce the transmission power and also enhance the network throughput through mitigating the medium contention. However, there is a price should be paid for this benefit since the shrinking of transmission range strongly influenced the network connectivity owing to the decrease of the number of neighbor sensors connected to given one. Another significant effect is to schedule sensors to sleep when they are not in use, without disturbing spatial coverage and global connectivity of the sensing field. The reliance of the connectivity on the number of running sensors and transmission range greatly complicates analysis.

The sensor coverage problem can be classified into either a k-coverage problem or 1-coverage problem. In k-coverage problem, each point or target in the area required to be covered by minimum k different working sensors. However, in the 1-coverage problem, each point and target in the sensing field should be covered by minimum one active sensor. Most of the time, network coverage issue is mainly related to the energy consumption of network [14-19]. In this work, the Minimize Usage – Extend Life (MUEL) Wireless Network Simulator has to be developed for simulate network operations for wireless sensor node networks. This approach to extending wireless sensor node network lifetimes can be of significant benefit to situations where a reduced coverage is acceptable; extending the network life by as much as 900% is possible.

SIMULATION SOFTWARE DESCRIPTION

Java Network Simulator

This wireless sensor network simulator was written in the programming language Java. The simulator is comprised of four Java classes: the Main class, the Node class, the Node Field Frame class, and the User Input class. The network simulator has been given a name which is to demonstrate the purpose of the project, Minimize Usage – Extend Life, or the MUEL simulator.

The principle algorithm followed by the simulator in operating in the wireless sensor network as shown in Figure 1.

```
once all of the nodes have been located and initialized
for loop, each loop simulates one minute of time passing
   for loop, the loop goes through every node
        if node is in active group
                set the node.state to 2 (active state)
                random nr. generated as a reading for the node to transmit
                the node transmits its reading
                1% of the power used in active state is accounted
                99% of the power used in low-power sleep state is
        else
                subtract the power for one minute in sleep state
        check if nodes power is < 50% (low power )
        check if node's power is < 5% (dead)
        check if any termination conditions have been met
        recheck conditions i)base node out of range, ii)some nodes out of
                range of each other iii) reestablish transmitNodes
```

Fig 1. Main algorithm of MUEL Simulator

Power Consumption

In order to understand the means by which power is consumed by the sensor node, a brief discussion of the different states, or modes of operation, of the sensor node must be included. The states that a sensor node may exist in are 1), an active state in which the sensor node is fully powered, listening and transmitting signals; and 2) a sleep state in which the sensor node is reduced to the minimum required to maintain memory and allow it to awake and return to an active state.

The Mica Mote, by Crossbow Technologies, has typical power usage characteristics for wireless sensor nodes. These power usage values for the various components and operational levels will be used in the wireless sensor network simulator, MUEL. These power usage values are given in the following Table 1.

Table 1: Current used in Crossbow MICA2 Mote

	Value	units
Micro Processor (Atmega128L)		
current (full operation)	6	ma
current sleep	8	ua
Radio		
current in receive	8	ma
current xmit	12	ma
current sleep	2	ua
Logger		
Write	15	ma
Read	4	ma
Sleep	2	ua
Sensor Board		
current (full operation)	5	ma
current sleep	5	ua

So, the determining factors are the initial power available for the sensor node, and the amount of time the sensor node spends in that state.

Microcontroller

The microcontroller unit on the wireless sensor node is a small computer set in an integrated circuit. Its components would typically consist of a simple central processing unit, CPU, a clock component, the input / output channel connections, and memory. This unit is also where the operating system of the wireless sensor node would be maintained and ran. From the table it can be seen that the microcontroller in its full-power states requires 6 milli-amps, mA, of current, and 8 micro-amps, µA, of current.

Sensing Unit

The sensing component of the wireless sensor node is that component which measures or takes the reading of whatever the node is supposed to monitor. From the table, it can be seen that the sensing unit may operate in one of two states: the active sensing state will require 5 mA of current to power it, and the sleep state of the sensing unit will require 5 µA of current to power it.

Radio

This is the component that will receive radio messages from other wireless sensor nodes, be they regular nodes or the base node. From the table it can be seen that the radio may operate in two states; active and sleep. In the sleep state, the radio will require 2 µA of current to power it; in the active state, the radio will require 8 mA to receive, and 12 mA of current to transmit.

Coverage

It is necessary to define coverage, and to establish how a wireless sensor node will be able to establish a positive reading, or make a measurement or reading of the parameter it is to be monitoring. In this simulation, it will be assumed that a wireless sensor node will be able to take a reading in a pure circular coverage area, and the intensity of the parameter that is being monitored will behave as for a radio signal, where the strength of the signal varies inversely with the square of the distance from the monitor. Strength α i/d^2 Simply stated, the equation above represents the strength of the measurement is inversely proportional to the square of the distance between the wireless sensor node and the distance at which the measurement is taken.

Enhancement and Complexity Analysis of Algorithm

One enhancement that is readily available is to check if there are any nodes in the same coverage Group that are also within a very close proximity to each other. If this were the case, the two wireless sensor nodes could be paired up and only one of them run at a time, and staying in the sleep state in the off time. This would theoretically prolong the life of the wireless sensor node, and therefore the network system. Examples of pairs of wireless sensor nodes can be seen in the following illustration. It can be seen that nodes N87 and N55, N88 and N135, and nodes N136 and N15 could be paired together as shown in Figure 2. Consider if these pairs of nodes were in the same coverage Group; in an application designed to minimize usage and extend network life, it would certainly make sense to not have the pair of nodes active at the same time.

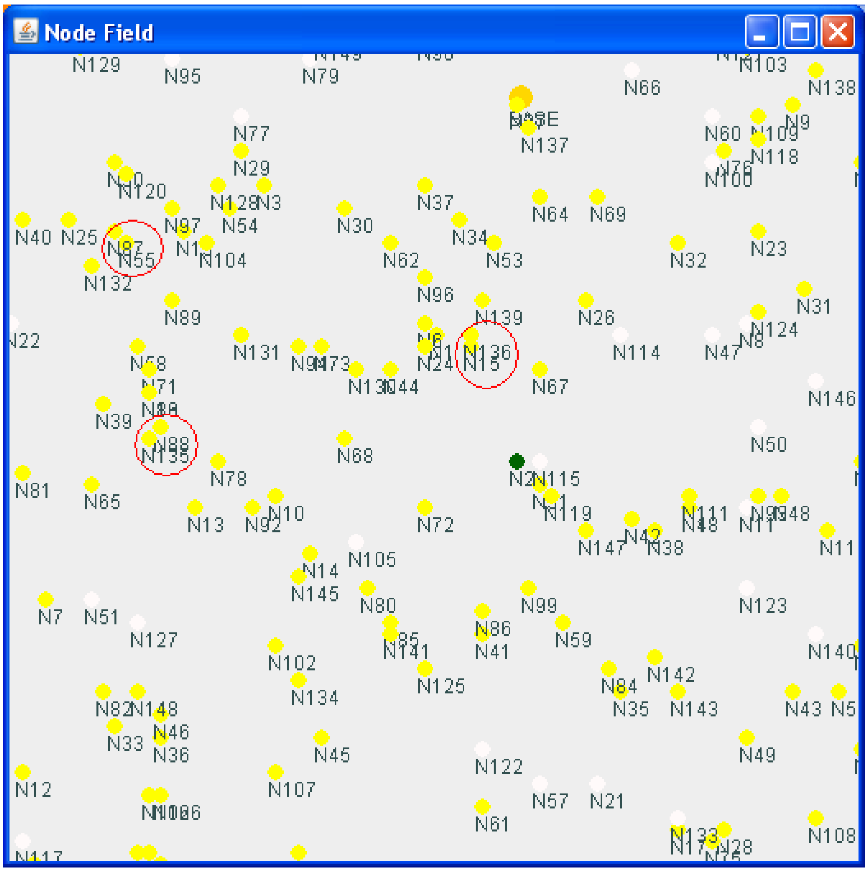


Fig 2. Display of output window with nodes near each other

This enhancement was implemented in the class Main.java in the method check Duplicate Coverage(). The first step was to create a method that would check every node against every other wireless sensor node to see if

1. The nodes were in the same coverage Group
2. To see if the nodes were less than 2 meters apart.

If both of these conditions were true, in the simulation, the node's Boolean value node. Is a Pair would be set to true. This is checked in the Main.java file on line #575, and an adjustment to the node's power supply is made on the next line.

Another enhancement to the algorithm would be to lift the requirement that two wireless sensor nodes be in the same coverage group to form a "pair". This would leave the check of two nodes against each other being only "are these two node's within two meters of each other?" There is a slight modification to the method check Duplicate Coverage(), which eliminates the condition that the two nodes being checked against each other are in the same coverage group.

The main algorithm of this simulation can be written as a function of the form f(n) = O(g(n)). Here, the function g(n) is the algorithm that is simulating our wireless network system, and the variable n represents the number of values that the function will work on; in this case n represents the number of wireless sensor nodes in our system. In the algorithm of the simulation, n, the number of wireless sensors in the network operates on every other wireless sensor node in the following methods:check Duplicate Coverage(), check Nodes Outside Trans Range Of Each Other(), and establish Transmit Node(). Check Duplicate Coverage() is the method that implements modifications for Enhancement #1 and Enhancement #2. This method checks every node against every other node for both the conditions: 1) is the node being checked in the same coverage group, and 2) is the node being checked within two meters of the initial node. If both of these conditions are met, the algorithm uses only one of the nodes at a time during an active duty cycle, thus saving energy for those two particular wireless sensor nodes.

In the method check Nodes Outside Trans Range Of Each Other(), the distance between the node in question and the original node is checked. The algorithm saves the smallest distance between the original node in question, and all of the other nodes in the system. If this minimum distance turns out to be greater than the expected transmission range of the wireless sensor nodes, then this node will be effectively out of range of the whole system.

The third method, establish Transmit Node(), checks every node against every other node to find a node that is within transmission range, and the range between the node being checked and the base node is minimized. This algorithm continually sets the transmission node at the furthest distance from the original node and chooses one that is in the direction of the base node, so that the chain of transmission nodes will ultimately reach the base node.

All of these algorithms are similar to sorting algorithms and are a type of quadratic equation. The order of complexity of these algorithms, using “big-O” notation, is $O(n^2)$.

RESULTS AND DISCUSSION

Initial Simulation Configuration

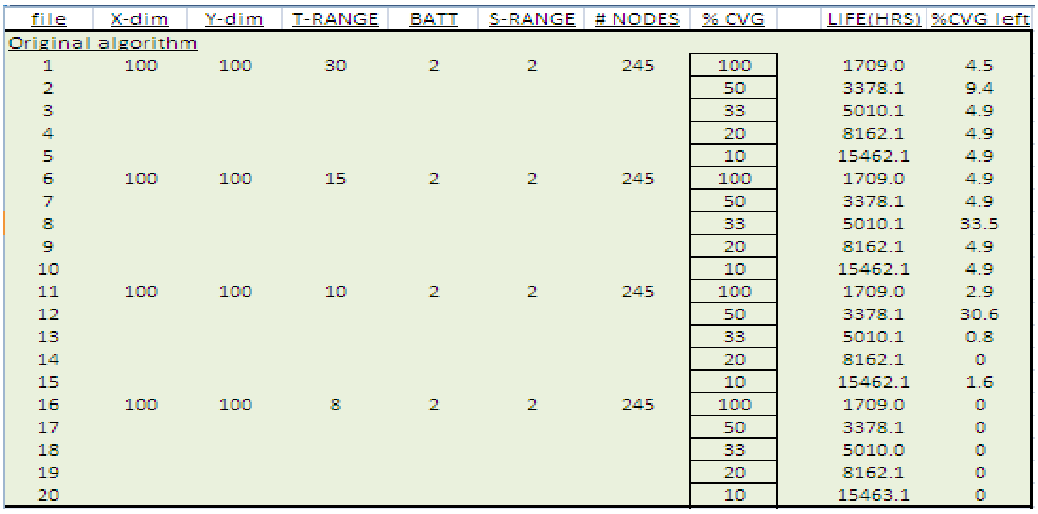
The results from several simulations are presented in Table 2 and 3. Simulations were run using inputs of 100 meters by 100 meters for the dimensions of the surveillance area, a sensing range of 2 meters, battery power roughly equivalent to two AAA batteries, 2.0 amp-hours. The variables for each simulation were 1) the distance of the transmission range for the wireless sensor nodes, and 2) what percentage of nodes was used during the active cycle. Transmission ranges of 30, 15, 10, and 8 meters were used, and the percentages of nodes used during the active cycle were 100, 50, 33, 20, and 10%.

The key observations made regarding the results are:

- Perhaps due to the programming of the simulations, the divergence in the resultant lifetimes of the wireless network was very small, for simulations that had similar parameters: surveillance area dimensions, sensing range, number of nodes
- In the second set of simulations in which network life lasted much longer, the divergence of the lifetimes was greater, probably due to the fact that the network lifetime was much greater
- There were simulations where the percentage of sensing coverage that was left at the end of the simulation was great, greater than 15%, which was a termination condition; as expected, these simulations terminated when the base node became out of range of the rest of the wireless sensor nodes; also, as expected, this type of simulation termination was more prevalent in simulations with a shorter transmission range, 8 meters or 10 meters. As the percentage of sensor nodes decreased during the active cycle, the extension of the network lifetime was seen to increase by an expected ratio; for example, when 100% of the nodes were used during the active duty cycle, the network lifetime was approximately 1709 hours, regardless of the transmission range of the sensor nodes. When 50% of the nodes were used during the active duty cycle, the network lifetime was 3378 hours. If there were no overhead power loss, one would expect a network lifetime of 2 × 1709, or 3418 hours. This is 98% of the expected network lifetime, which is excellent. When 33% of the nodes were used during the active duty cycle, the network lifetime was 5010 hours. If there were no overhead power loss, one would expect 3 × 1709, or 5127 hours. The lifetime actually seen from the simulator, 5010 hours, is 97.7%. Continuing, when 10% of the nodes are used during the active duty cycle, the network lifetime was 15,462 hours. This is 90% of what would be expected if there were no overhead power loss. Making similar calculations in the second run of simulations, the extension of network life is much less, percentage-wise. For simulations in which 50%, 33%, 20%, and 10% of the nodes were active during the duty cycle, the network lifetimes were 93%, 87%, 77%, and 60%, respectively, of what would be expected if there were no overhead power loss. The cause for the lifetimes to be much less than in the first run of simulations is that the parameters chosen for the second run made

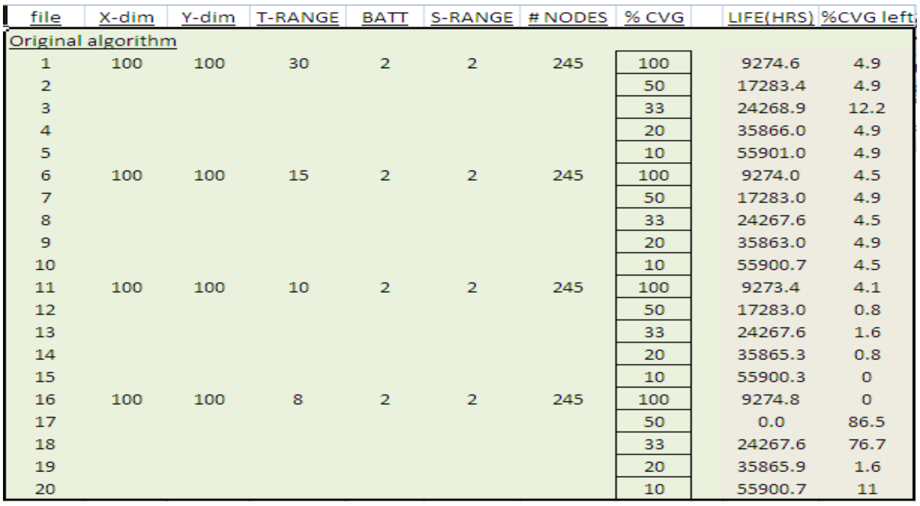
the network run much longer, there was therefore much more of the power being used for overhead of the network operation. Graph of Network Life vs. Number of Subgroups as shown in Figure 3

Table 2: Network lifetimes, first configuration



file	X-dim	Y-dim	T-RANGE	BATT	S-RANGE	# NODES	% CVG	LIFE(HRS)	%CVG left
Original algorithm									
1	100	100	30	2	2	245	100	1709.0	4.5
2							50	3378.1	9.4
3							33	5010.1	4.9
4							20	8162.1	4.9
5							10	15462.1	4.9
6	100	100	15	2	2	245	100	1709.0	4.9
7							50	3378.1	4.9
8							33	5010.1	33.5
9							20	8162.1	4.9
10							10	15462.1	4.9
11	100	100	10	2	2	245	100	1709.0	2.9
12							50	3378.1	30.6
13							33	5010.1	0.8
14							20	8162.1	0
15							10	15462.1	1.6
16	100	100	8	2	2	245	100	1709.0	0
17							50	3378.1	0
18							33	5010.0	0
19							20	8162.1	0
20							10	15463.1	0

Table 3: Network lifetimes, second configuration



file	X-dim	Y-dim	T-RANGE	BATT	S-RANGE	# NODES	% CVG	LIFE(HRS)	%CVG left
Original algorithm									
1	100	100	30	2	2	245	100	9274.6	4.9
2							50	17283.4	4.9
3							33	24268.9	12.2
4							20	35866.0	4.9
5							10	55901.0	4.9
6	100	100	15	2	2	245	100	9274.0	4.5
7							50	17283.0	4.9
8							33	24267.6	4.5
9							20	35863.0	4.9
10							10	55900.7	4.5
11	100	100	10	2	2	245	100	9273.4	4.1
12							50	17283.0	0.8
13							33	24267.6	1.6
14							20	35865.3	0.8
15							10	55900.3	0
16	100	100	8	2	2	245	100	9274.8	0
17							50	0.0	86.5
18							33	24267.6	76.7
19							20	35865.9	1.6
20							10	55900.7	11

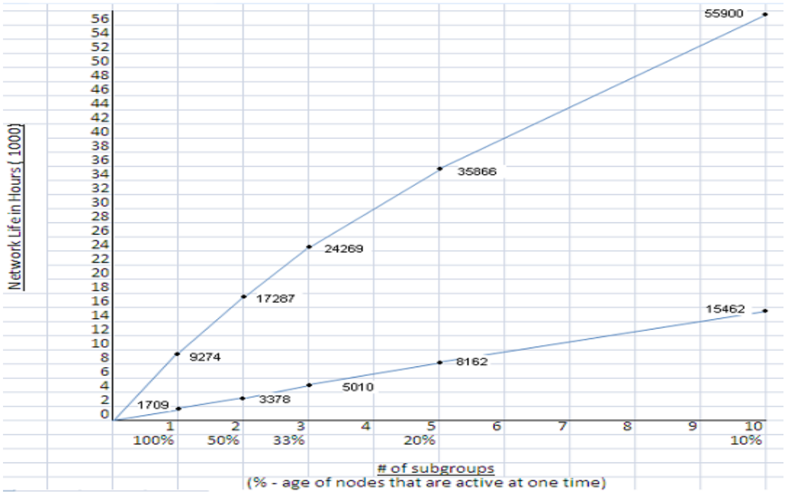
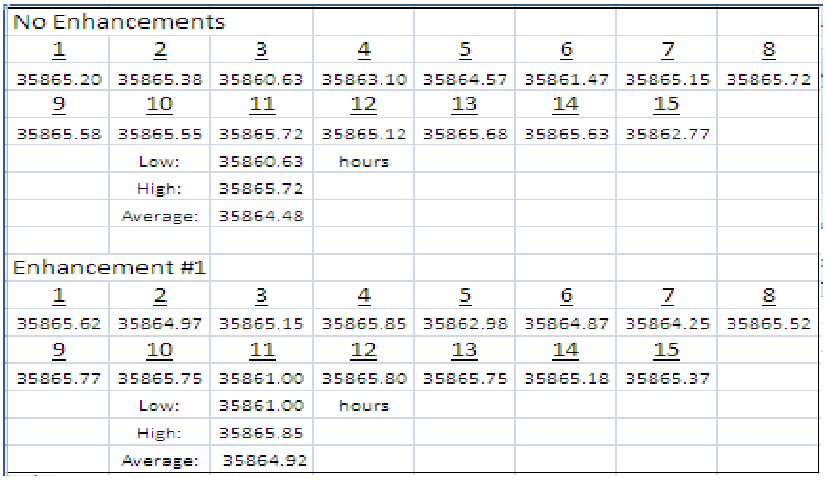


Fig 3. Graph of Network Life vs. Number of Subgroups

Enhancement 1

Fifteen simulations were run in the MUEL wireless network simulator with the following parameters: 100m by 100m surveillance area, 245 wireless sensor nodes, sensing range of 2m, 15m transmission range, and 20% of the nodes active at one time in each coverage group. The results from the simulator with no enhancements and the results with Enhancement #1 are presented in the following Table 4.

Table 4: Network lifetimes with Enhancement #1



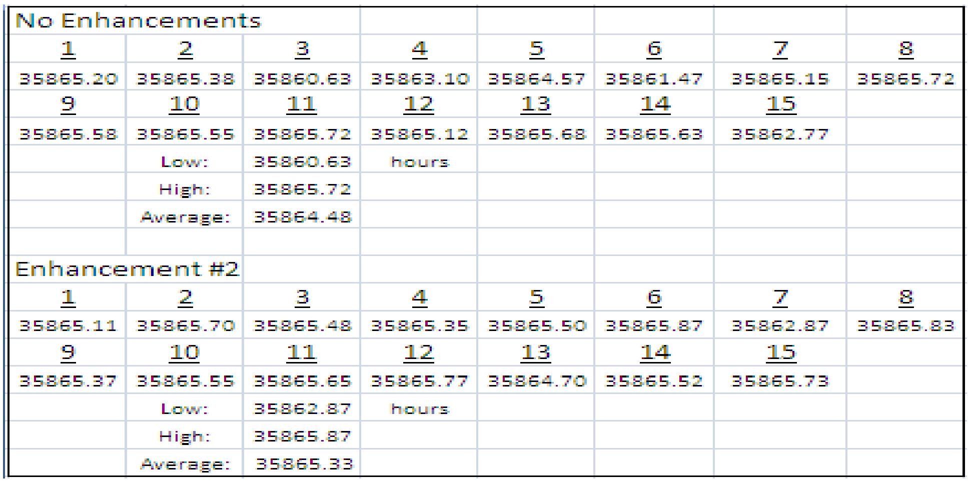
No Enhancements							
1	2	3	4	5	6	7	8
35865.20	35865.38	35860.63	35863.10	35864.57	35861.47	35865.15	35865.72
9	10	11	12	13	14	15	
35865.58	35865.55	35865.72	35865.12	35865.68	35865.63	35862.77	
	Low:	35860.63	hours				
	High:	35865.72					
	Average:	35864.48					
Enhancement #1							
1	2	3	4	5	6	7	8
35865.62	35864.97	35865.15	35865.85	35862.98	35864.87	35864.25	35865.52
9	10	11	12	13	14	15	
35865.77	35865.75	35861.00	35865.80	35865.75	35865.18	35865.37	
	Low:	35861.00	hours				
	High:	35865.85					
	Average:	35864.92					

The average of the simulations with no enhancement is 35,864.48 hours, and the standard deviation of the values is 1.67115; i.e., in a sample of numbers whose average is around 35,900, there is not much variance in the values. The average of the simulations with Enhancement #1 is 35,864.92 hours, with a standard deviation of 1.32278; again, there is not much variance in the sample of values for Enhancement #1. However, the difference between the averages from the no enhancement group to the Enhancement #1 group is 0.44 hours. If we consider an average transmission time in the simulation of 0.75 seconds (a one second transmission time for reporting a reading, and a 0.5 second transmission time for a node to relay a reading), this would equate to 2112 transmissions. 0.44 hours ÷ 0.75 seconds/transmission × 60 seconds/minute × 60 minutes/hour = 2112 transmissions. So, even though the difference in the overall lifetime of the network with Enhancement #1 is not statistically significant, the enhancement does demonstrate that approximately 2000 more transmissions would be possible with Enhancement #1, as would be expected.

Enhancement 2

Fifteen simulations were also run in the MUEL simulator with Enhancement #2 having been implemented. The same network parameters were used with Enhancement #2 as with the previous simulations. The results from the simulations are presented in the Table 5.

Table 5: Network lifetimes with Enhancement #2



No Enhancements							
1	2	3	4	5	6	7	8
35865.20	35865.38	35860.63	35863.10	35864.57	35861.47	35865.15	35865.72
9	10	11	12	13	14	15	
35865.58	35865.55	35865.72	35865.12	35865.68	35865.63	35862.77	
	Low:	35860.63	hours				
	High:	35865.72					
	Average:	35864.48					
Enhancement #2							
1	2	3	4	5	6	7	8
35865.11	35865.70	35865.48	35865.35	35865.50	35865.87	35862.87	35865.83
9	10	11	12	13	14	15	
35865.37	35865.55	35865.65	35865.77	35864.70	35865.52	35865.73	
	Low:	35862.87	hours				
	High:	35865.87					
	Average:	35865.33					

Again, it can be seen that the divergence among the results is not great; the standard deviation in the results from the simulations with Enhancement #2 is 0.74. The difference between the average of the simulations with no enhancement and that with Enhancement #2 is 0.85 hours. Using the same values as were used in the calculation for Enhancement #1, this translates into 4080 more transmissions. 0.85 hours ÷ 0.75 seconds/transmission × 60 seconds/minute × 60 minutes/hour = 4080 transmissionsAgain, in relation to the overall life of the network in hours, this is not a statistically significant increase in network life, but it does demonstrate an increase of approximately 4000 Transmissions in the life of the network, as would be expected.

CONCLUSION

The Minimize Usage – Extend Life (MUEL) Wireless Network Simulator was developed to simulate network operations for wireless sensor node networks. The simulations produced results that would be expected: for identical network conditions, a network that is using 50% of the nodes during an active duty cycle, compared to a network that is using 100% of the nodes during an active duty cycle, will last approximately twice as long. There will, however, always be “overhead” power used in the operation of the network, e.g., power used to recompute transmission nodes after one node has depleted its energy and been removed from the network system. As smaller and smaller percentages of nodes are active at one time, the overhead power cost becomes greater and greater, so that while the overall network life is extended, the scale that that life of the network is increased becomes less and less. As demonstrated in the results, the longer the network runs, overhead power costs will become considerable. In the first run of simulations in which 100% of the nodes were active in the duty cycle, when 10% of the nodes were active in the duty cycle, the network lasted 90% of the time if there were no overhead power loss. In the second run of simulations, when 100% of the nodes were active in the duty cycle, the network had a lifetime of approximately 9,274 hours, regardless of the transmission range of the nodes. If there were no overhead power loss, when 10% of the nodes were active during the duty cycle, we would expect network lifetimes of 92,740 hours. What was observed was a network lifetime of approximately 55,900 hours, only 60% of the possible network lifetime. Both of these simulations used 245 nodes, 2 meter sensing range, and 100 meter by 100 meter surveillance area. Still, this approach to extending wireless sensor node network lifetimes can be of significant benefit to situations where a reduced coverage is acceptable; extending the network life by as much as 900% is possible. Areas for future research in this area might include assigning the sensor nodes into coverage groups so that when one coverage group is active, the actual coverage of the surveillance area will be more dispersed, instead of just according to the numbering of the nodes. There could also be advances in the overhead power used by the sensor nodes, so that as the networks become bigger and bigger, the actual extension of the network life will be maximized as much as possible.

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