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Development of an Energy Efficient Data Fusion Technique for Homogenous Distributed Sensor Networks

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Abstract: *Wireless distributed sensor network has brought about increased accuracy in monitoring application which is the major purpose of WSNs. However, data redundancy and reliability are some issues posed by such network hence the introduction of data fusion technique increased the accuracy of data and reduce data redundancy and make it faults tolerant. While some of the technique focused on reducing data redundancy. Some focused on achieving fault tolerance in the network and some focused on both and most of the researchers did not consider integrating data fusion with energy conservation technique for increased network lifetime. In this work, an energy efficient data fusion technique is presented using Telosb xm1000. During cluster heads selection, we take nodes fused data and neighbour nodes fused data in sending the average fused data to the cluster head which serves as the intermediary between the nodes and the base station into consideration. In addition, we take advantage of node by dividing the nodes in two sect, sect A and sect B by each sect sampling at 5secs and sleeping for five minutes interval to improve the lifetime of the nodes by hundred percent instead of traditional method. In this scheme, sampling by half improves the efficiency of energy and prolong the lifetime in a distributed way. The experimental results indicate our scheme is better than some other scheme in aspects of energy consumption and the lifetime of the network.*

Keywords: *WSN, data fusion, data aggregation, energy, temperature.*

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are highly distributed networks with tiny and low-cost sensing and communication gadgets**,** called **Sensor Nodes** (SNs) [1]. These wireless sensor networks are littered with nodes ranging from sparse networks of 10 to populated networks with 100,000 nodes collecting data from the environments. Distributed architecture, ad-hoc, wireless communication and other attributes made them suitable for a wide variety of applications ranging from engineering, environment science, and health service to military [2] Wireless sensor nodes are limited in energy, memory, transmission range, and computational power. To manage the scarce resources of the SNs, embedded operating systems like Tiny Operating System (TinyOS) was developed. TinyOS is a component-based OS developed using NesC programming language for managing the resources of the constrained sensor nodes for efficient running and prolonged lifetime [3].

The task of each SN is to sense the environment and report the data to the Base Station (BS) using localized routing decisions. A BS is usually a powerful computer with more computational power, energy and memory. In a large WSN, reporting the data by each node to the BS is not possible because of their limited transmission range [5]. To achieve this, Wireless Sensor Networks adopt in-network Data Fusion (DF) process along with routing algorithm to route the consolidated data until it gets to the BS [4]. DF is the process of gathering and summarizing the data for statistical analysis. It provides advantages such as reporting consolidated data, reducing data redundancy and improving network lifetime.

DF is also used to overcome sensor failures, technological limitations, and spatial and temporal coverage problems. It is generally regarded as the use of techniques that combine data from multiple sources and gather this information in order to achieve inferences, which will be more efficient and potentially more accurate than if they were by means of a single source [6] The term efficient, in this case, can mean more reliable delivery of accurate achieved information, more complete, and more dependable. The data fusion can be implemented in both centralized and distributed systems. In a centralized system, all raw sensor data would be sent to one node, and the data fusion would all occur at the same location. In a distributed system, the different fusion modules would be implemented on distributed components. Data fusion occurs at each node using its own data and data from the neighbours [7]. In this work, a remote environmental monitoring system is proposed based on TinyOS and incorporating a data fusion model for accuracy and prolonged network lifetime

The emergence of distributed sensor network has brought about increased accuracy in monitoring application which is the major purpose of WSN. However, data redundancy and reliability are some issues posed by such network hence the introduction of data fusion technique reduce data redundancy and make it faults tolerant. While some of the technique focused on reducing data redundancy. Some focused on achieving fault tolerance in the network and some focused on both and most of the researchers did not consider integrating data fusion with energy conservation technique for increased network lifetime. In this work, an energy efficient data fusion technique is presented.

Distributed Wireless Sensor Network

A distributed system is a system consisting of a collection of autonomous machines connected by communication networks and equipped with software systems designed to produce an integrated and consistent computing environment. Distributed systems enable people to cooperate and coordinate their activities more effectively and efficiently. The key purposes of the distributed systems can be represented by: resource sharing, openness, concurrency, scalability, fault-tolerance and transparency [8].

2.1 Components of Distributed Wireless Sensor Network

Component of distributed wireless network consist of the sensor nodes, cluster head, the base station.
Sensor node: is a node in a sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network.
Cluster head: A node in a cluster that is responsible for collecting data from the member nodes in its cluster and relay these data to the Base Station.
Base station: A base station is a radio receiver/transmitter that serves as the hub of the local wireless network which all the data gather from the clusters is been sent to through the cluster head [9].

2.2 Wireless Sensor Nodes

Some common component of wireless sensor nodes are: TelosB shown in figure 1, MicaZ, Zolerata, TelosB. TelosB XM1000 mote is an open source platform designed to enable cutting-edge experimentation for the research community. The XM1000 bundles all the essentials for lab studies into a single platform including; USB Programming capability, an IEEE 802.15.4 radio with integrated ChipCon CC2420 antenna for communication, with Processor model of MSP 430, User & Reset Buttons with extended memory and an optional sensor suite.

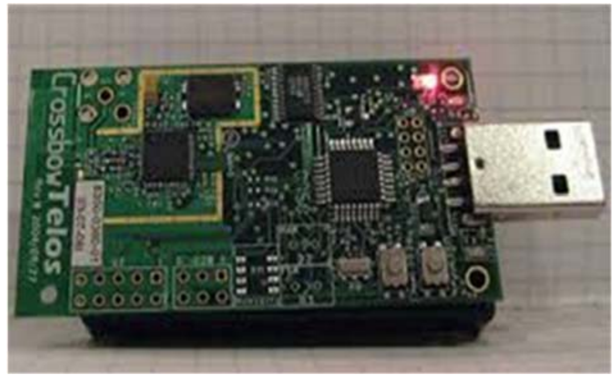

Figure 1: Telosb XM1000

2.3 Preamble

The method used in carrying out the development of an energy efficient data fusion technique for homogenous distributed sensor network, which included design of homogenous distributed sensor network, the data fusion model, Energy Conservation Scheme, Network Life Time Modelling, Performance Evaluation to achieve the objectives were described. Starting with the block diagram shown in Figure2. Each block is described in the subsequent section.

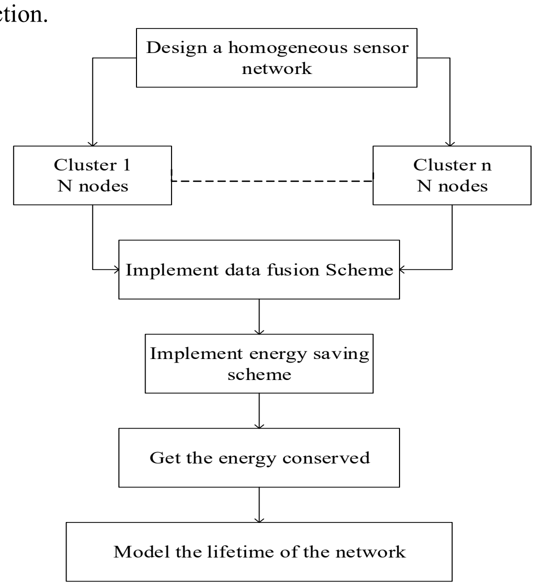

Figure 2: Block diagram of the system

2.4 Homogenous Distributed Sensor Network

Each cluster consists of sensor nodes which is XM1000 based on TelosB and which as a flash memory in which the code enters, also it uses chipcon for communication (cc2420). Each of the sensor in the cluster in the Figure 3 reads temperature, for that reason it is called homogenous. After sensing, each of the sensor in the cluster sends to the cluster head, simply because it’s only the cluster head that can sends to the base station using the IEEE 802.15.4 technology.

The architecture designed for this system is shown in Figure 3 which is well suited for these sensor networks, all the nodes in the network are homogeneous and begin with the same initial energy, the nodes are divided into two section so as to prolong the life span of the network. While the first section of the network is sensing for the first 5 seconds the other section is being set to sleep for the first 5 minutes and interchange after 5 minutes. This model uses a clustering scheme shown in the network structure in Figure 3.

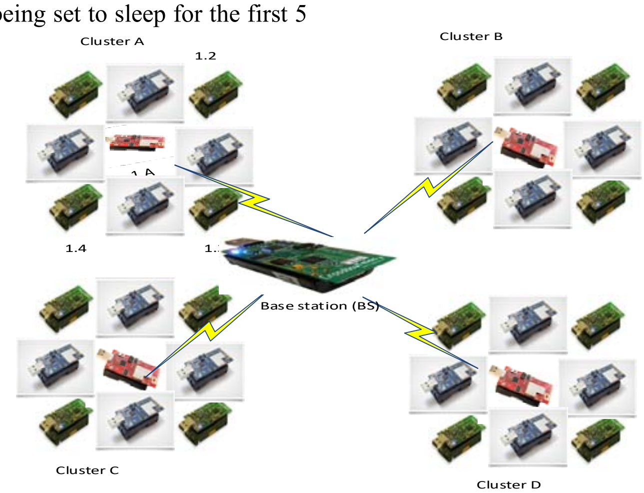

Figure 3: System architecture

3. The Data Fusion Model

The data fusion in the network is taking place at every stage in the network, for example if the first node senses temperature value and route the value to its neighbour and the neighbouring nodes aggregates the value and send to its neighbour using format of the fusion shown in Figure 4.

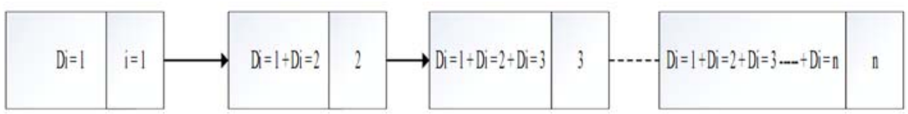

Figure 4: Data fusion model

The fusion is based on Equation 1.

$$DF = \frac{(CR_n + P_n)}{nF} \qquad (1)$$

where CR_n is the current node data reading, P_n is the previously fused reading received from a neighbour node, nF is the number of nodes involved in the fusion.

Each cluster has a cluster head which collects data from its cluster nodes members, aggregates it sends it the aggregated value to the next nodes which will indicate the number of nodes involved in the aggregation then add it to the new value gathered and also aggregates before sending it to the next nodes with the number of aggregated nodes involve before reaching it, after all the nodes have sensed the parameter and done with the aggregation the aggregated value is been sent to the cluster heads which will now communicate the final fused data from the cluster to the BS. For example in figure 4, nodes 1.1 senses a temperature value of 31.5 degrees and sends it to node 1.2 with the address of 31.5/1, and node 1.2 now add its own value and fuse before sending it to the next node with the address of 31.5/2 to show the number of nodes that has fused the data before reaching it, and these process goes through all till it reach node n and then node n send it fused data with address of /n to indicate the number of nodes involved so far and sends it to the cluster head then the cluster head communicate with the base station. Similarly, there exist other cluster heads such as 1.B, etc. These cluster-heads, in turn, form a cluster with node 1 as their cluster-head. This pattern is repeated for each cluster nodes reporting directly to the BS. The BS forms the root of this network and supervises the entire network.

3.1 Energy Conservation Scheme

The block diagram of the energy saving scheme is shown in the Figure 5.

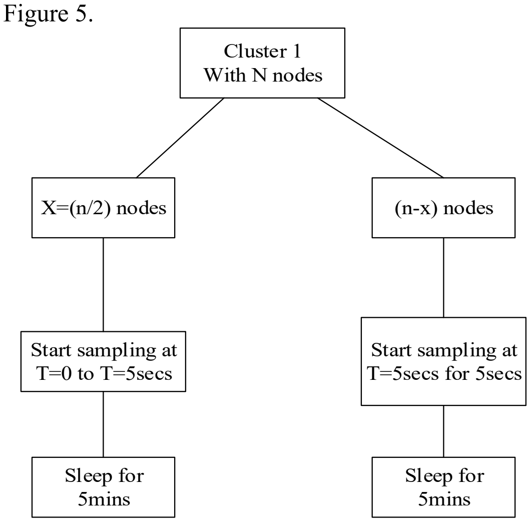

Figure 5: Block diagram for the energy saving scheme

As can be seen in Figure 5,

I. The first block which is cluster that consists of the XM1000 motes which is been deployed to the cluster. This process happens for all the N clusters in the network.
II. The second block is the stage where the nodes are divided into two sets, in each set, nodes are selected randomly, and these happens for each cluster to N clusters.
III. For the third block, these is the stage in which the sampling takes place, for the sampling process, the first set of nodes start sampling for the first 5seconds and repeats this process for all the clusters involved.
IV. The fourth block is the stage at which the first set of nodes is set to rest for the next 5 minutes and after these durations the next set of nodes transmit after 5minutes for the next 5 seconds.

3.2 Network Life Time Modelling

The modelling of the lifetime of the network is based on the individual lifetime of the sensor nodes in the sensor network as shown in equation 3.1 is used to get the power consumed during communication by each node. At the end of that the energy utilised for 24 hours will be calculated using equation .2

$$\boldsymbol{P_c = N_T\,[P_T(T_{on} + T_{st}) + P_{out}(T_{on})] + N_R[P_R(R_{on} + R_{st})]} \quad \textbf{(2)}$$

Where,
P_c is the power consumed, N_T is the numbers of times transmission is ON
P_T is the power consumed by the transmitter
T_{on} is the time transmission is ON,
T_{st} is the transmission startup time, P_{out} is the output power
N_R is the numbers of times the recievers is ON,
P_R is the power consumed by the reciever,
R_{on} is the time the reciever is ON and
R_{st} is the time the recievers stops.
The number of days that a 3-volt battery will take before it gets exhausted will be computed using equation 3 by that the lifetime of the network will be calculated using equation 4.

3.3 Performance Evaluation

The metrics as mention in the objectives are energy conservation and lifetime.

Energy Conservation: Two scenario was considered. The first was when the energy conservation was not considered and the second was when the energy conservation was considered and the two were compared to get the energy conservation of the new scheme according to equation 3

$$E_{c=E_{ws-}E_s} \quad (3)$$

Where E_c is the energy conserved
E_{ws} is the energy with the scheme

Network Life Time: two scenarios were considered as well, that is when the lifetime was not considered and when the lifetime was considered as shown in the equation 4
Network Lifetime = lifetime without the scheme - lifetime with the scheme

$$N_L = \sum_i^n ND_{li} \quad (4)$$

When N_L is the network lifetime
ND_L is the node lifetime

4. IMPLEMENTATION

4.1 Preamble

At the end of the process of system development, results were obtained, and stated objectives were achieved. The developed system was tested, and its performance evaluated to determine if the system works as was intended. This chapter will cover the readings carried out, evaluation of the energy conservation and the network lifetime and results obtained.

4.2 Power consumption Result

Half of the nodes sample for 5seconds and sleep for 5minutes, so the number of time data fused node sample, in one hour will be 12 times, in 24 hours, it will sample for 12 times × 24hrs = 288 times

since we are considering the introduce schemed it sample by 2 set i.e. first set sample by 5sec and sleep for 5mins while the other set starts sampling and sleep for 5mins also there reducing the sampling time by half therefore the introduce scheme:

Mode	**Transmitting mode**	**Receiving mode**
Vscope	0.999V	1.0299
Time division (Δt)	21ms	21ms
Energy used	0.38395mJ	0.3958mJ
Energy used with the scheme (24 hr)	55.29mJ	56.99mJ
Energy used without the scheme (24 hr)	110.58mJ	113.98mJ

Sampling time = 288/2 = 144 times
Transmitting current (TX) = 8.5mA
Receiving current (RX) = 18.8mA i.e. the receiving current
Note: from the value for Tx and Rx, it shows that the receiving current is higher than the transmitting current
Pout = 25 dbm i.e. the output power of the transmitter
Ton - time that Tx is on i.e. 144×5sec= 720sec
Ron - time that Rx is on i.e. 144×5sec= 720sec
Tst - Tx start up time
i.e. start up time + settling time = 100us + 2us = 102us = 102×10^-6= 0.000102sec
Tst - Rx start up time
i.e. start-up time + settling time = 100us + 2us = 102us = 102×10^-6= 0.000102sec
Nt - No of times Tx is on per unit time = 144times
Nt - No of times Tx is on per unit time = 144times-1= 143times. This is because the first node from the transmitting node is not receiving from any other node but is the first to send to other nodes

Pt - power consume by the receiver= 8.5mA × 10^{-3} × 3= 0.0255W
Pr - power consume by the transmitter = 18.8mA × 10^{-3} × 3= 0.0564W
The difference between Pt and Pr=0.0564- 0.0255= 0.0309w
Pc = power consume by the Telosb sensor using my scheme
Tx = 8.5mA
Rx = 18.8mA
Pout = 25dBm
Ton = 720sec
Ron = 720sec
Tst = 0.000102sec
Tst = 0.000102sec
Nt = 144times
Nr = 143times
Pt = 0.0255W
Pr = 0.0564W
Pc = Nt [Pt (Ton + Tst) + Pout (Ton)] + Nr [Pr (Ron + Tst)]
Pc = 144 [0.0255 (720 + 0.000102) + 25 (720)] + 143 [0.0564 (720 + 0.000102)]
Pc = 144 [18.36 + 18000] + 143 [40.608]
Pc = 2594643 + 5806.94
Pc = 2600450.78
Pc = 2.6 × 10^6W
Using the existing Scheme

Half of the nodes sample for 5sec and sleep for 5mins, so the number of time node sample in one hour will be 1hrs /5mins= 12 times.
So for 1 full day it will sample for 12 times × 24 = 288times
TX current= 8.5mA I.e the transmitting current
Rx current= 18.8mA I.e. the receiving current
Note: from the value for Tx and Rx, it shows that the receiving current is higher than the transmitting current
Pout = 25dBm I.e. the output power of the transmitter
Ton - time that Tx is on i.e. 288×5sec= 14400sec
Ron - time that Rx is on i.e. 288×5sec= 1440sec
Tst - Tx startup time
i.e. startup time + settling time = 100us + 2us = 102us = 102×10^-6= 0.000102sec
Tst - Rx startup time
i.e. startup time + settling time = 100us + 2us = 102us = 102×10^-6= 0.000102sec
Nt - No of times Tx is on per unit time = 288times
Nt - No of times Tx is on per unit time = 288times-1= 287times. This is because the first node for the transmitting node is not receiving from any other node but is the first to send to other nodes.
Pt - power consume by the receiver= 8.5mA × 10^-3 × 3= 0.0255W
Pr - power consume by the transmitter = 18.8mA × 10^-3 × 3= 0.0564W
The difference between Pt and Pr = 0.0564 - 0.0255= 0.0309W
Pc = power consume by the Telosb sensor using the energy saving scheme
Tx = 8.5mA
Rx = 18.8mA
Pout = 25dBm
Ton = 1440sec
Ron = 1440sec
Tst = 0.000102sec
Tst = 0.000102sec
Nt = 288times
Nr = 287times
Pt = 0.0255w
Pr = 0.0564w
Pc = Nt [Pt (Ton + Tst) + Pout (Ton)] + Nr [Pr (Ron + Tst)]
Pc = 288 [0.0255 (1440 + 0.000102) + 25 (1440)] + 287 [0.0564 (1440 + 0.000102)]
Pc = 288 [36.73 + 36000] + 287 [81.22]
Pc = 10378575 + 23308.99
Pc = 10401883.994
Pc = 10.4 × 10^7W

From the two result in Table 2 we can deduce that using the original scheme the power consumed 10.4 × 10^7w which is higher than 2.6 ×10^7w gotten from the introduce scheme. From this result we can conclude that the power consumed using the introduce scheme is less than power consume using the original scheme because power managing scheme is introduced thereby increasing the lifetime of the nodes and it will increase the lifetime of the nodes by hundred percent.

The Energy Used in Transmission
E(joules) = Vscope ÷ (106 × 1.5) × 2.91 (Δt)
0.999 ÷ (159) × 2.91 × 21 × 10^-3
= 0.38395mJ
Result for Energy Used in Receiving E(joules) = Vscope ÷ (106 × 1.5) × 2.91(Δt)
1.0299 ÷ (159) × 2.91 × 21 × 10^-3
= 0.3958mJ

where 2.91 is the value of the 2 **AA** batteries powering the mote , note 2AA is a battery known for durability.
Δt is the time division read from the oscilloscope?
Vscope is the voltage of the oscilloscope.

From the result in the table about it shown that the energy consumes while transmitting is a bit less than the energy used when the nodes are receiving because the receiving node received from several nodes while the transmitting or the nodes send from each different nodes.

After deploying the developed system to the cluster field, readings were taken between the developed system and existing system respectively. This was done in order to evaluate the performance of the developed system based on energy conserved and the lifetime of the system with a standard existing system. Temperature readings were acquired after subjecting the system to intensive performance testing

After deploying the developed system to the cluster field, readings were taken between the developed system and existing system respectively. This was done in order to evaluate the performance of the developed system based on energy conserved and the lifetime of the system with a standard existing system. Temperature readings were acquired after subjecting the system to intensive performance testing which is shown with in Figure 6.

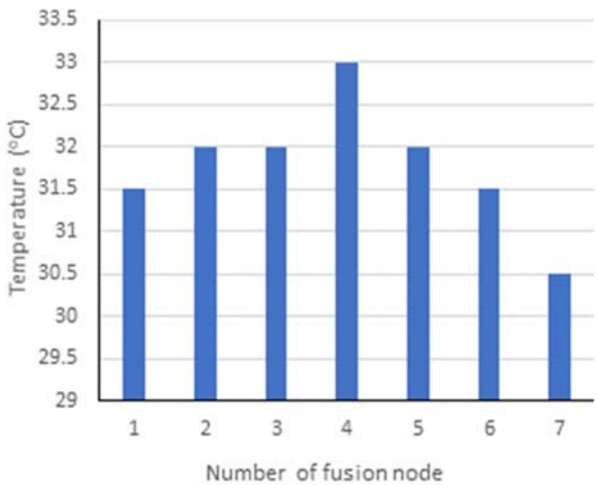

Figure 6: Fused temperature reading from the clusters heads

Table 1: Temperature Reading

Temperature Reading (°C)	Number of Fused Times
31.5	1
32	2
32	3
33	4
32	5
31.5	6
30.5	7

Table 2: Day 1 temperature readings obtained from the existing system

S/N	Time (sec)	Temperature (°C)	Range (m)	Power Consumed (J/ms)
1	5	30	5	0.035
2	5	30.5	5	0.075
3	5	30	5	0.1125
4	5	31.5	5	0.15
5	5	32	5	0.1875
6	5	31.5	5	0.225
7	5	30	5	0.265

Table 3: Day 1 temperature readings from the developed system

S/N	Time (sec)	Temperature(°C)	Range	Power Consumed (J/ms)
1	5	31.5	5	0.021
2	5	31	5	0.042
3	5	32	5	0.063
4	5	31	5	0.084
5	5	32	5	0.105
6	5	33	5	0.126
7	5	31	5	0.147

Table 4: Day 2 temperature reading from the existing system

S/N	Time (sec)	Temperature (°C)	Range	Power Consumed (J/ms)
1	5	31.5	5	0.4125
2	5	32	5	0.45
3	5	30.5	5	0.4875
4	5	31	5	0.525
5	5	33	5	0.5625
6	5	32	5	0.6
7	5	31	5	0.637

Table 5: Day 2 temperature reading and power consumed from the developed system

S/N	Time (sec)	Temperature (°C)	Range (m)	Power Consumed (J/ms)
1	5	30	5	0.231
2	5	31	5	0.252
3	5	32.5	5	0.273
4	5	33	5	0.294
5	5	31.5	5	0.315
6	5	32	5	0.336
7	5	32	5	0.357

Temperature Readings from Different Locations

Table 6: Temperature reading from the developed system

S/N	Time (sec)	Temperature (°C)	Range (m)
1	5	32	5
2	5	31	5
3	5	31	5
4	5	31.5	5
5	5	31.5	5
6	5	31	5
7	5	32	5

Table 7: Temperature reading from the developed system

S/N	Time (sec)	Temperature (°C)	Range (m)
1	5	32	5
2	5	32	5
3	5	31	5
4	5	32	5
5	5	31	5
6	5	31.5	5
7	5	32	5

Table 8: Temperature reading from the developed system

S/N	Time (sec)	Temperature(°C)	Range (m)
1	5	31.5	5
2	5	32	5
3	5	31	5
4	5	31	5
5	5	32	5
6	5	31	5
7	5	31	5

Table 9: Temperature reading from the developed system

S/N	Time (sec)	Temperature(°C)	Range (m)
1	5	32	5
2	5	31.5	5
3	5	31.5	5
4	5	31	5
5	5	32	5
6	5	31	5
7	5	31.5	5

Table 10: Temperature reading from the developed system

S/N	Time(secs)	Temperature (°C)	Range (m)
1	5	31	5
2	5	31.5	5
3	5	31	5
4	5	31	5
5	5	30	5
6	5	31	5
7	5	30	5

S/N	Time (sec)	Temperature (°C)	Range (m)
1	5	32	5
2	5	31.5	5
3	5	31	5
4	5	31	5
5	5	32	5
6	5	31.5	5
7	5	31	5

Table 12: Performance evaluation

	DAY 1	DAY2
	Temperature (°C)	Temperature (°C)
Developed system	30.8	31.5
Existing system	31.6	32.4

The percentage of the temperature for two days were computed, and the value was gotten to be 80% efficient, which is based on Equation 3.

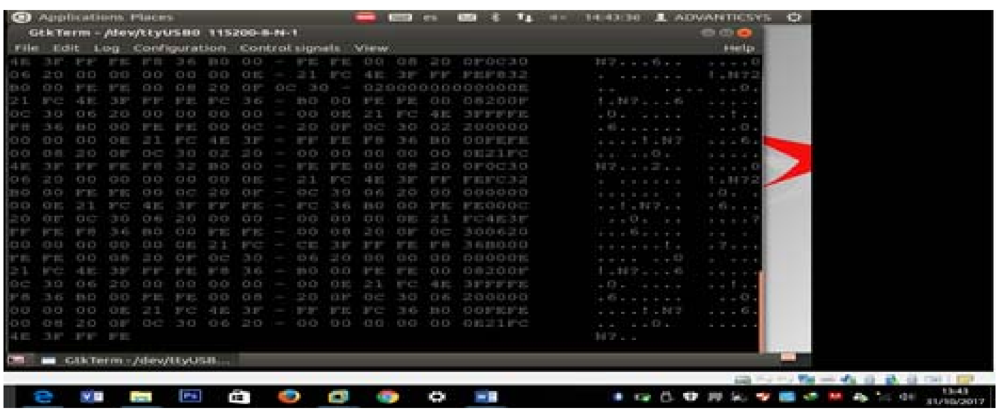

Figure 7: Mote readings from advantic system software

4.3 Discussion of Result

The power consumed when the scheme is being implemented was lower than when the scheme is not implemented, however the method used for homogeneous distributed sensor network to get energy efficient will function efficiently when used. The low energy consumed was as a result of dividing the nodes in the clusters into two set and assigning which to transmit and which set to sleep. The major drawback of the project was from the low number of motes. The graph of all the reading were plotted for Temperature as the measurement were taken for two consecutive days. The output of the graph was shown in Fig 8 to 10 respectively. The percentage error of the existing system was calculated for temperature.

After deploying the developed system to the cluster field, readings were taken between the developed system and existing system respectively. This was done in order to evaluate the performance of the developed system based on energy conserved and the lifetime of the system with a standard existing system. Temperature readings were acquired after subjecting the system to intensive performance testing

Table 6 shows the result obtained for the performance evaluation. The percentage error obtained from both systems as reported above shows that the result of the temperature of the developed system give a better reading compared to the existing system by a factor of 0.30, this variation is due to differences in the accuracy of the method used for both systems.

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Figure 8: Graph of temperature for day 1

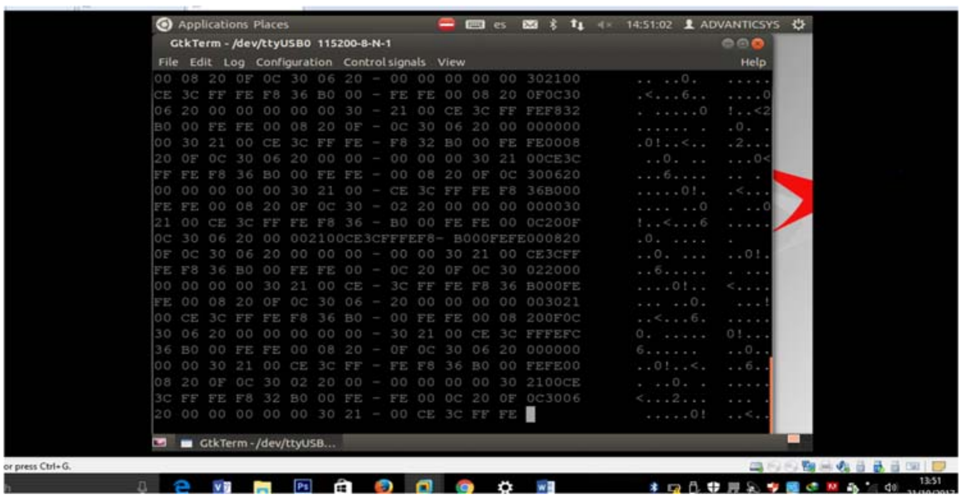

Figure 9: Day 1 temperature readings

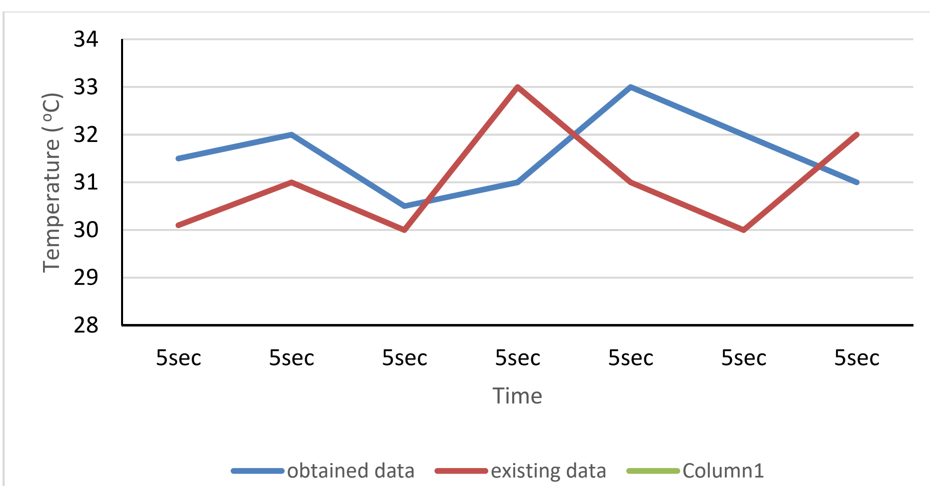

Figure 10: Graph of temperature for day 2

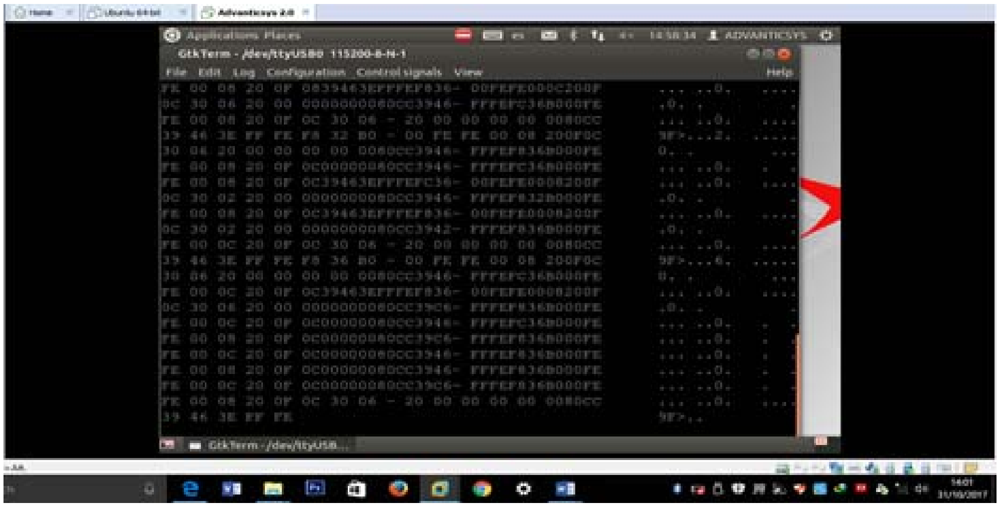

Figure 11: Temperature reading for day 2

5. CONCLUSION

In this project, we present how efficient energy can be conserved to prolong the lifetime of homogenous distributed sensor network. We also introduced a scheduled sampling technique, that is, half sampling and half sleeping (or rest). Also, the use of embedded operating system was introduced. Lastly the network lifetime was modelled, which allows the system to last long by almost 100% compare to the existing scheme**.** The system can be improved upon in the future considering Multiple Sensor Integration. Other sensors such as light sensor, soil temperature sensor, atmospheric pressure sensor, and devices such as wind vane, anemometer and rain gauge can be integrated in order to attain high rate of environmental monitoring.

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