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Efficient Use of Wireless Sensors for Data Collection in Precision Irrigation

[1]M. Marimbi, [1]M. Munyaradzi,[1]B. M. Nyambo, [2]E. Mashonjowa

[1] Computer Science department, [2]Physics department

University of Zimbabwe, Harare, Zimbabwe

bromishmars@gmail.com, mmunyaradzi@science.uz.ac.zw, nyambo@science.uz.ac.zw, emashonjowa@gmail.com

Abstract—This paper looks at how to optimize data collection from the wireless sensor nodes and analysis of this data for an efficient irrigation scheduling in order to optimize water usage. In this research we design a model system which integrates optimum node placement and data aggregation to see the combined effect on the efficiency of the wireless sensor network (WSN) that is in terms of latency, power consumption and utilization, network life span (i.e. node mortality). Issues looked into included the optimum placement of the sensor nodes, traffic aggregation and protocols for cooperative data forwarding. Models of different topologies were designed and evaluated through simulations to come up with the best model that achieves optimum placement to minimize the number of nodes without compromising on the readings as well as incorporating data forwarding and aggregation. The model was cost effective as it displayed significant improvement in efficiency, power utilization, consumption, network lifetime and can be adopted for ordinary farmers in developing countries like Zimbabwe.

Index Terms— Wireless Sensor nodes, optimal node placement, data aggregation, power utilization, performance modeling, ZigBee

1 Introduction

From the 1980s to present wireless sensor technology has evolved immensely, which have resulted in a new generation of inexpensive compact sensors based on a number of high-density technologies. Advances in IEEE 802.11a/b/g-based wireless networking and other wireless systems such as Bluetooth, ZigBee and WiMax are now facilitating reliable and ubiquitous connectivity [12]. Inexpensive processors that have low power-consumption requirements make possible the deployment of sensors for a plethora of applications. Commercially-focused efforts are now directed at defining mesh, peer-to-peer, and cluster-tree network topologies with data security features and interoperable application profiles [2]. Our study looked at the effect of different topologies on the efficiency of WSN and also it's combined effect with data aggregation. Our major drive was the application of these WSN technologies in precision irrigation. We envisage a situation where WSN are used to gather field data which can be used for calculating the evapotranspiration and irrigation is done to replace lost water without human intervention. A lot of research has been conducted in this field. For example, in the field of crop monitoring, wireless sensors have been developed to gather data on leaf temperature, chlorophyll content and plant water status. Based on these data, farmers are able to detect problems at an early stage and implement real-time solutions. The major limitation of the WSN networks is their dependency on battery power so efforts have been made to come up with WSN with high energy efficiency, culminating in the thrust on node placement and data aggregation techniques that try to reduce network load by eliminating redundancy.

In this research we designed a model system which integrates optimum node placement and data aggregation to see the combined effect on the efficiency of the WSN that is in terms of latency, power consumption and utilization, network life span i.e. node mortality .Optimum placement whether dynamically or statically has equal advantages of maximizing network lifetime, improving network efficiency, reduce number of sensors to be used and increase the coverage thereby improving data collection which in turn would have a direct impact on the level of precision in our precision irrigation system.

2 Literature review

2.1 Introduction

A lot of research in wireless sensor networks use in automated irrigation has been done already. A wireless solution for intelligent field irrigation system dedicated to Jew's ear planting was developed in Lishui, Zhejiang, China in 2009. Instead of conventional wired connection, the wireless design made easy installation and maintenance. The hardware architecture and software algorithm of wireless sensor/actuator node and portable controller, acting as the end device and coordinator in ZigBee wireless sensor network respectively, were elaborated in detail. It was based on Zig Bee technology, but was not implemented on large scale [19].

In [19], Feliciano et al developed a conceptual model of an automated irrigation system. They developed a prototype automated irrigation system using wireless modules and in situ root zone soil moistures, capacitance sensors, electro-mechanical and temperature sensors .The wireless sensors were deployed throughout the greenhouse and root zone data was transmitted to a computer control system.

The researchers in [7] designed a model wireless sensor based system with 6 SM200 soil moisture sensors ,3 repeaters and a gateway connected to a PC.Mesh topology which supports multipath communication and hence more reliable ? was used. The nodes were able to relay data to a repeater over a 20m distance, but the desired maximum data loss of 5% could not be fulfilled. Battery life, remote access and internet data transport worked well. The system's weak points were signal losses, sensor performance, high cost and packaging.

Delta T Devices (UK), Netafim (IS), Decagon (US) and Crossbow (US) are among the major suppliers of wireless sensor equipment and were very active in the WSN research. However the equipment is still expensive and uses a lot of energy to overcome the variable damping of electromagnetic waves in crops under fluctuating weather conditions [7].

In [20], Zhang, et al proposed a WSN for precision agriculture using Bluetooth. Although challenges such as battery life and transmission latency exist in his application, his work gives hopes for the future of WSN in agriculture applications [16].

In [1], Abhinav V. et al designed a protocol which they named Distributed Sensor Webs Routing Protocol (DSRP) and a WSN system which they implemented to monitor water status and control irrigation for ornamental crops. However, this system was developed for compatibility with EM50 data loggers of Decagon Devices Inc which poses a question of compatibility with other devices from different vendors.

Most research about the use of WSN in the field of precision agriculture and horticulture has so far been carried out in Australia and North America [10].

A number of publications confirm that at the current stage WSN are not reliable enough, cannot withstand outdoor climatic conditions, lose communication, are not fault tolerant and use too much power despite the fact that a lot of research has been carried out to address these different issues. This unreliability is caused by many factors which range from the sensor hardware, software, network infrastructure, protocols. If it's in precision irrigation where data about the field is needed for scheduling and decision making , we see more dependency on the data collection (i.e. how efficient and accurate is the data collected). Thus our main thrust for this research was to focus on efficient data collection for effective irrigation management and water conservation as well as improving on our yield.

In [10] they also confirmed that although automating irrigation is easy, automated systems are not necessarily water efficient. This seems to be true because automation is fully dependant on the collected data from the sensors, and there are many factors which can affect the efficient collection of this data which starts from the sensor itself, the network or transmission medium, necessary calculations and processing of the data, and placement of the sensor nodes in the network etc.

Since battery powered equipment are more favourable, there is need for both equipment and communication protocols improvement so as to conserve energy and increase reliability under outdoor agricultural conditions.

Since we are looking forward to implementation of these systems in large scale agriculture, we need to subdivide the field into regions, taking note of the soil type and any relevant data that might help us in our decision making during scheduling for us to get more accurate readings and hence more precise irrigation. FLOW AID for example, made a Decision Support System (DSS) and then used this method [6]. They divided the land into plots and then measured amount of water used against soil type, water availability and yield. They used the 866-868 MHz frequency band for the sensors.

2.2 Data Aggregation

Because of power and transmission range limitations, data dissemination in sensor networks is typically carried out as a collective operation, in which sensors collaborate to get data from different parts of the sensor network to the information sinks. One way of performing power-efficient data collection in sensor networks is to process the data as it flows from information sources to sinks. This technique is commonly referred to as (in-network) data aggregation and can be quite effective at conserving power [4]. Data aggregation tries to minimize traffic load (number/length of packets) through eliminating redundancy. In this study we adopted the duplicate suppression algorithm and directed diffusion paradigm. [13], [16], [9].

Let d_i be the shortest distance from the source S_i to the sink in the graph. As per datum the total transmissions needed for Random source model N_R is:

$$N_R = d_1 + d_2 + d_3 + \cdots d_n = sum(d_i) \quad (1)$$

Let the number of transmissions needed for optimal source model be N_o .

Then $N_o \leq N_R$ must hold for it to be better. [8]

Proof:

Doing data aggregation optimally decreases the minimum number of edges needed compared to when the sources send information only using the shortest path.

Definition: let X be the diameter of a set S of nodes in a graph G.

If the source nodes $S_1, S_2, S_3 \ldots\ldots S_n$ have $X \geq 1$ a diameter the total number of transmissions N_o required for optimal data aggregation satisfies the following bounds:

$$N_o \leq (n-1)X + \min(d_i) \quad (2)$$

$$N_o \geq (n-1)X + \min(d_i) \quad (3)$$

Proof: (2) by constructing a data aggregation tree which consists of $(n-1)$ sources sending packets to the remaining source which is nearest to the sink. This tree has no more than

$N_o \leq (n-1)X + \min(d_i)$, edges hence optimum tree must have no more than this.

Definition: Fractional energy saving (FS) in Optimal Source model

$$FS = (N_R - N_0)/(N_R) \qquad 0 \leq FS \leq 1 \qquad (4)$$

The upper and lower bounds of FS derived from (2) and (3) are:

$$FS \geq 1 - ((n-1)X + \min(d_i))/sum(d_i) \qquad (5)$$
$$FS \geq 1 - (\min(d_i) + (n-1)/sum(d_i) \qquad (6)$$

Assume that all the sources are at the same shortest path distance from the sink i.e.
$\min(d_i) = \max(d_i) = d$
Then we have:

$$1 - \frac{((n-1)X + d)}{nd} \leq \text{FS} \leq 1 - \frac{(d+n-1)}{nd} \qquad (7)$$
$$\lim_{d\to\infty} FS = 1 - 1/n$$

Sensors monitor the events of interest and send them to a gateway node where the end user can access it. Due to power limits and hardware constraints every sensor has a sensing range of r km and a communication range of 2r km. Sensor placement is according to their distance from the gateway node.
Let $S_1 \ldots\ldots S_n$ be the number of sensors, where S_1 is closest to the gateway node and S_N is furthest from the gateway node. S_i is the i^{th}sensor from the gateway node. Sensor placement
$\{d_i\}I = I^N$ According to distance between adjacent sensors d_i should satisfy the following constraints:

i. $0 < d_1 \leq r$

ii. $0 < d_i \leq 2r$

iii. for $2 \leq i \leq N-1$

iv. $c0 < L - \sum_{j=1}^{N} dj < r$ [8]

Yunxia Chen et al proposed a new performance metric, called lifetime per unit cost, to measure the utilization efficiency of sensors. Optimum placement whether dynamically or statically has equal advantages of maximizing network lifetime, improving network efficiency, reduce number of sensors to be used and increase the coverage thereby improving data collection, which in turn would have a direct impact on the level of precision in our precision irrigation system [8].

3 Methodology

An investigation into two aspects, namely node placement and data aggregation was carried out in the quest of trying to address the problem of efficient data collection which is dependent on the efficiency of the whole network. Many deterministic topologies (i.e. star, ring, mesh, kite, linear, pentagonal and some irregular ones) were designed and tested under simulation using OMNeT 4.2.1 simulator. The parameters which we used to test efficiency were latency, as data is propagated from all the sources to the sink. While many published papers aim at maximizing the lifetime, our aim was to maximize utilization efficiency and coverage for optimum data collection.

3.1 Experiment setup

Using OMNeT 4.2.1 simulator, different topologies were simulated, taking note of their effect on the network lifetime and also delays in packet propagation between nodes as data was transmitted to the sink. This data was then used to determine the best node placement and topology based on the improved lifetime and reduced delays in packet propagation between hops.

We assumed that the routing technique used is no-trivial and the network has no other constraints affecting it like transmit power and strength of the sensors. The performance parameters considered in this research were energy saving, delay, robustness, network lifetime and network performance
On energy saving, it is important to note that, aggregating information coming from sources reduces the number of transmissions, which in turn saves energy. The delay or latency associated with data aggregation as data from nearer sources is held at aggregators waiting for data from far sources in order to combine them.

Since energy is saved there is a decrease in marginal energy cost of connecting additional sources to the sink. This provides some degree of robustness to the sensed phenomena.
Network lifetime is a measure of the expected energy dissipation rate which determines how long the network will run perfectly before the nodes run out of power. Network Performance is measured as the number of events processed per second. It will be used also to evaluate the topology's efficiency.

3.2 Data aggregation

We chose the best network topology from the ones we designed and compared it with a random control topology both with aggregation and then without aggregation under simulation.We analyzed the analytical bounds of the energy cost and savings brought by data aggregation and found out that the greatest gains are obtained when the sources are close together and far away from the sink.

4 Results and Discussion

Figure 2 shows delay in ms versus number of hops for different node placement topologies. Analyzing Figure 2 shows that linear topology is very good for short distances between source and sink i.e. the number of hops are few so it will be ideal for small areas of less than 10 sensors per 1000 m^2. Pentagonal and Topology 1 are almost the same in delays but pentagonal gets poorer as the network size increases. Graph also shows field coverage for pentagonal was not in any way better than topology 1.
Topology 2 and 3 increases delays up to 5 hops and then increase in network size becomes insignificant on delays for up to 10 hops, then gradually increases again. We also observed that these two topologies are less efficient than topology 1, topology 4, ring and pentagonal topologies. We see that for less than 10 hops linear topology (Bus) is ideal if we want to sacrifice coverage to network speed, but topology 1 is better as it has both good network performance and good coverage.
Pentagonal and Ring are also good but they also have one drawback, which is short fall of coverage yet we desire both network efficiency in terms of packets or data forwarding and sensing area coverage. This makes topology 1 ideal.

Mesh shows gradual increase in delays as network size increases and also as routing table increases and becomes more complex due to many routes to be considered for packet forwarding, more energy will be needed . Mesh is advantageous if we're only concerned with coverage, and non battery powered wireless networks. The delays for all the topologies increases as the network size increases which means as the network increases there are many bottle necks which come into play, it also shows that the topology itself influence network performance and behavior. Figure 3 shows the efficiency of topology with and without aggregation as a timeline. We observe from Figure 3 that for both topologies the one with data aggregation has better efficiency than without .We also observe that optimal topology has more efficiency than the control topology. This brings us to the conclusion that data agregation is ideal for improved network performance and resource conservation in WSN.

We can observe from Figure 4 that both topologies with data aggregation have lower power utilization than without. This is due to the fact that data aggregation reduces network load by eliminating redundancy which degrades the performance of the network by increasing collisions, delay, and energy consumption thereby minimizing transmission power [14]. In network processing of data consumes less energy than data transmission so we can capitalize on that. We also investigated under simulation the high rate of death of nodes due to power dissipation and we can also observe that there is less death for up to 100 nodes per square km but for network sizes greater than that we see a drastic decrease in network lifetime due to increased node mortality. As number of nodes increases connections between nodes increases more routing and throughput requires more energy. Transmission distance increases thereby consuming more energy so that the nodes will lose energy at faster rates [15]. Figure 6 shows that power consumption increases insignificantly up to 125 nodes per km^2, but above that there is a sharp increase which is constituted by increased interference and in network processing between nodes due to their density [14]

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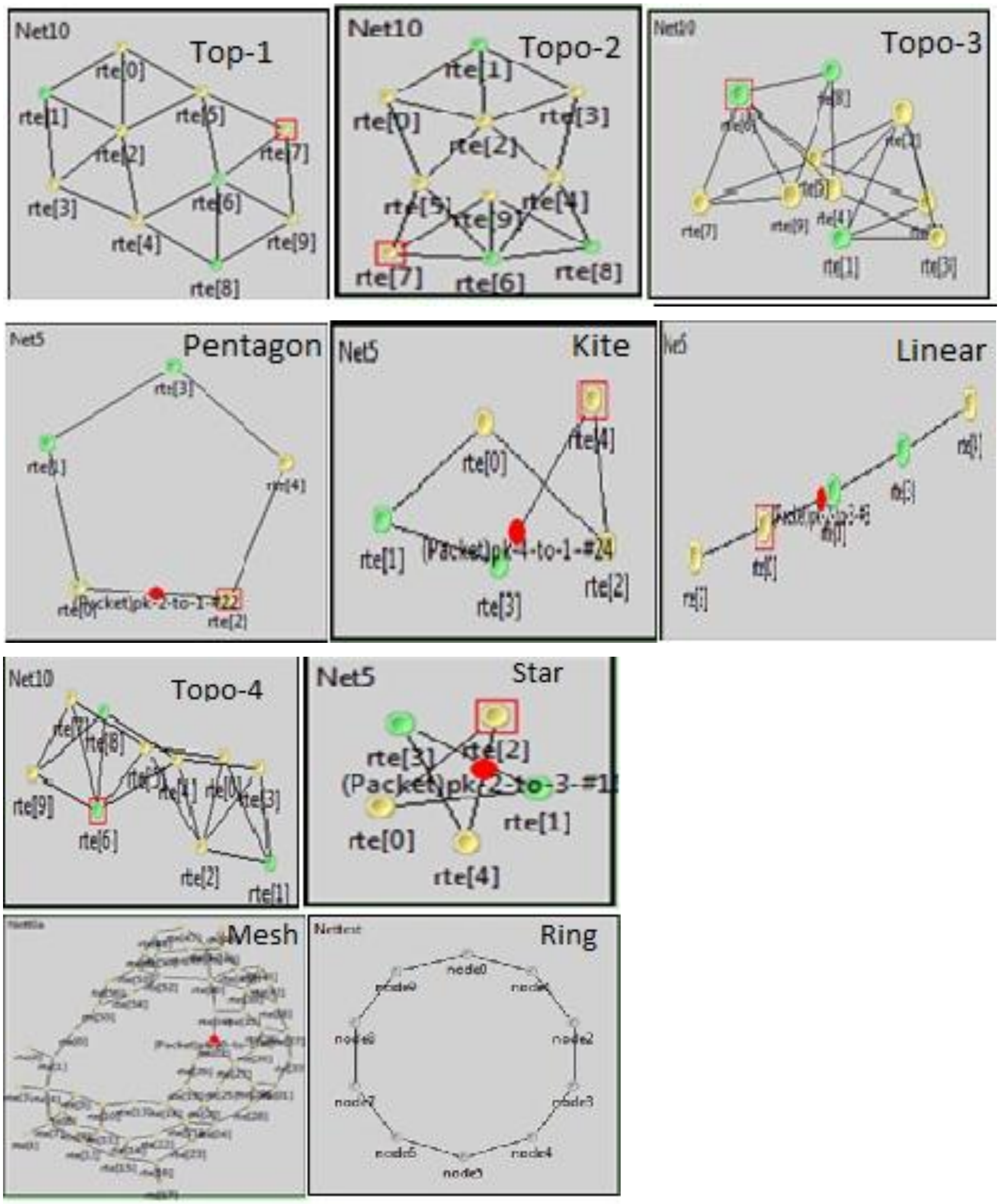

Figure 1: Topologies used in placing sensors in the field.

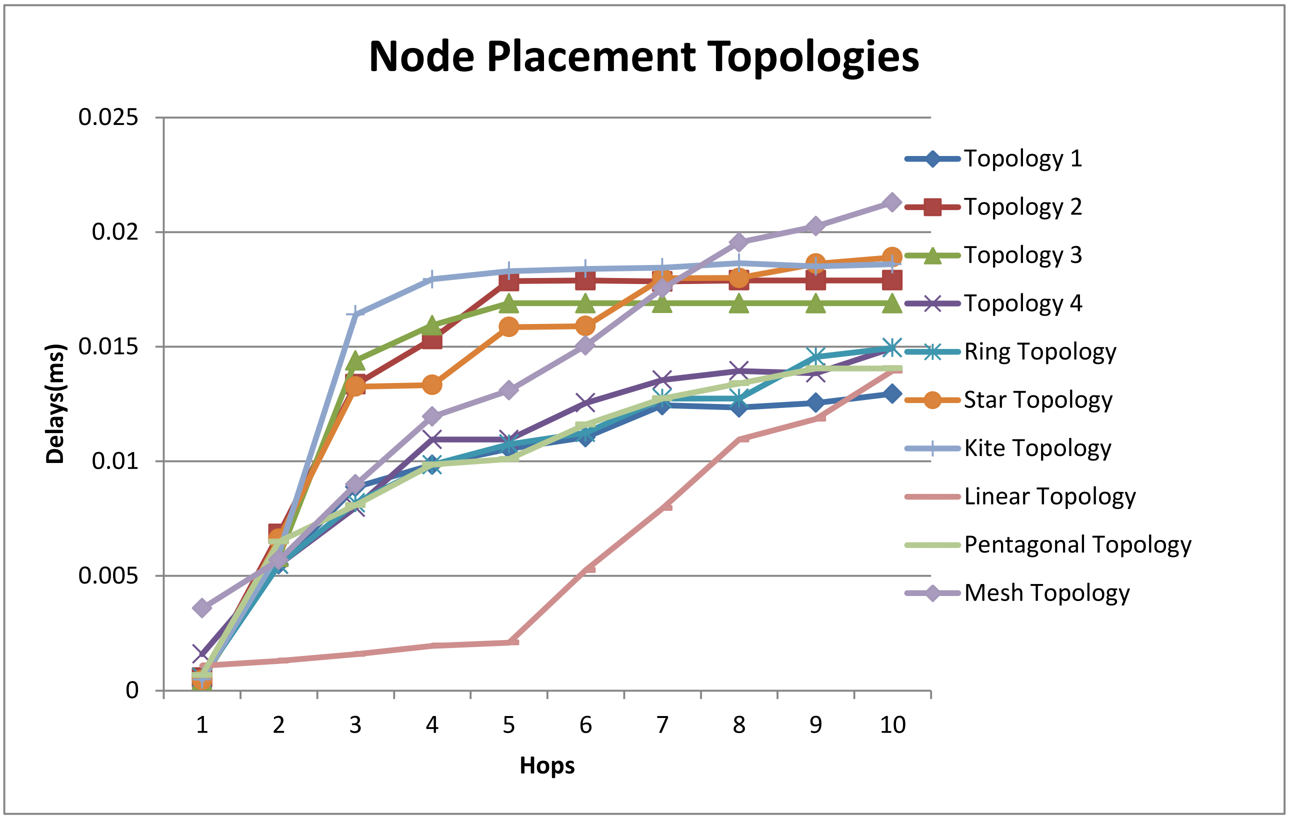

Figure 2: The relationship of delay of various node placement topologies with increase in network size.

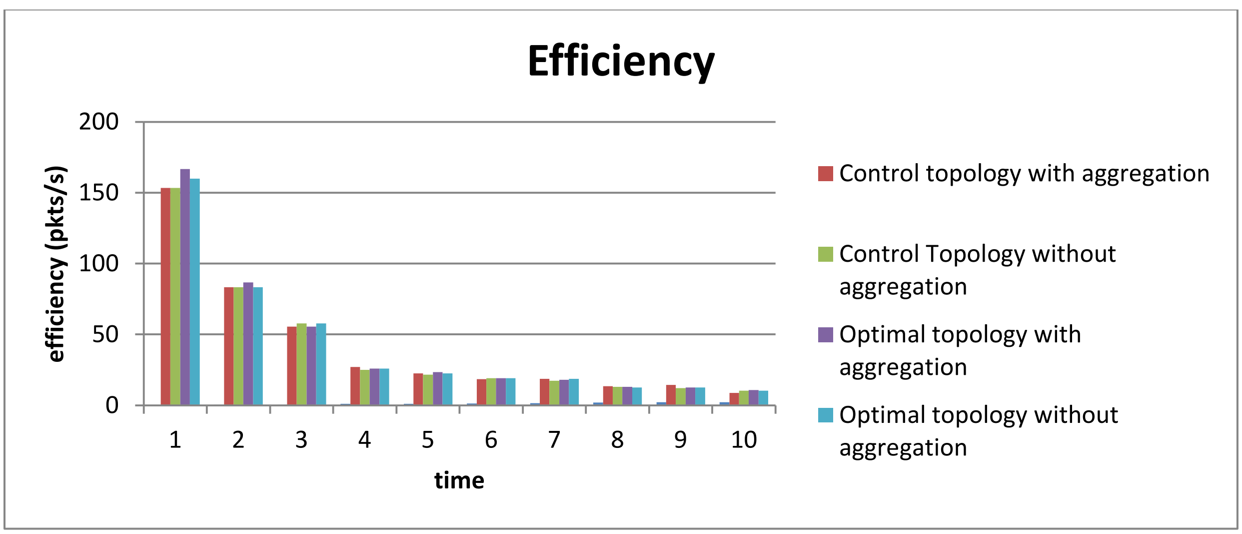

Figure 3: The efficiency of the optimal and control topologies with time.

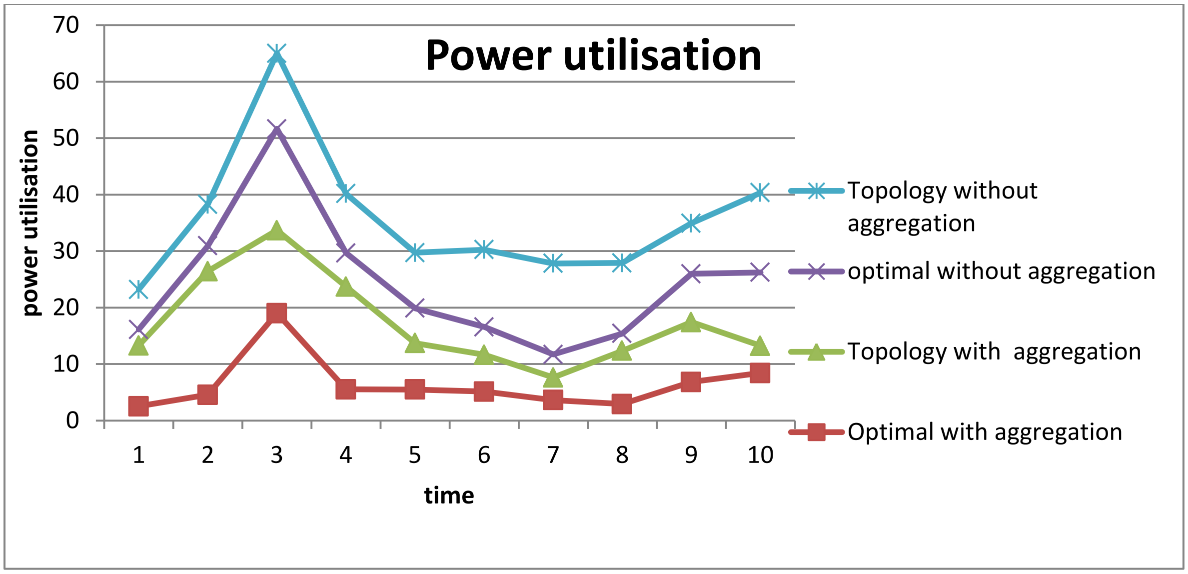

Figure 4: The relationship of power utilization and time for the optimal and the control topologies, with and without aggregation.

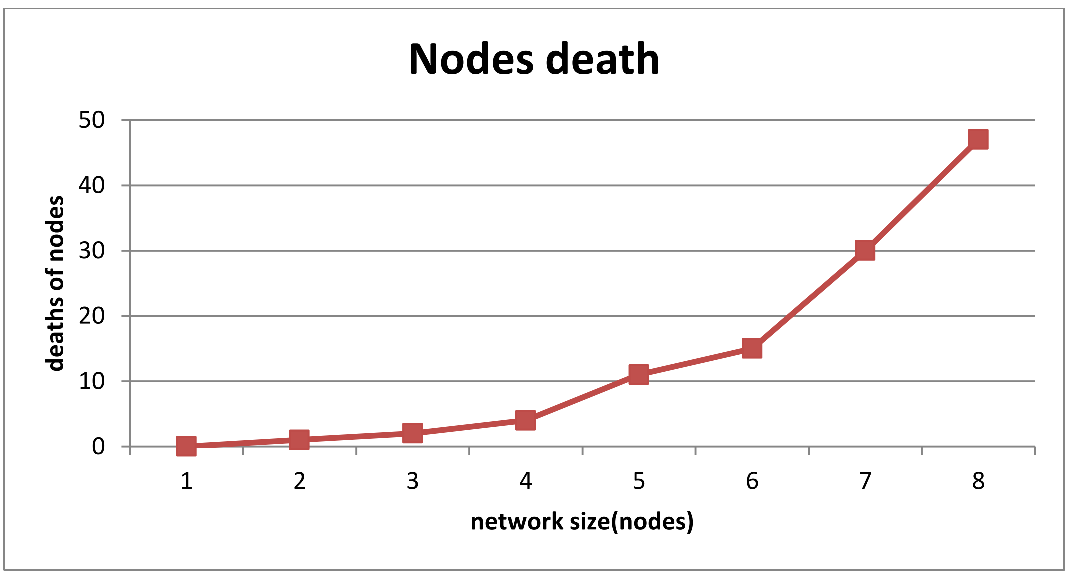

Figure 5: The number of deaths of nodes in relation to the increase in network size.

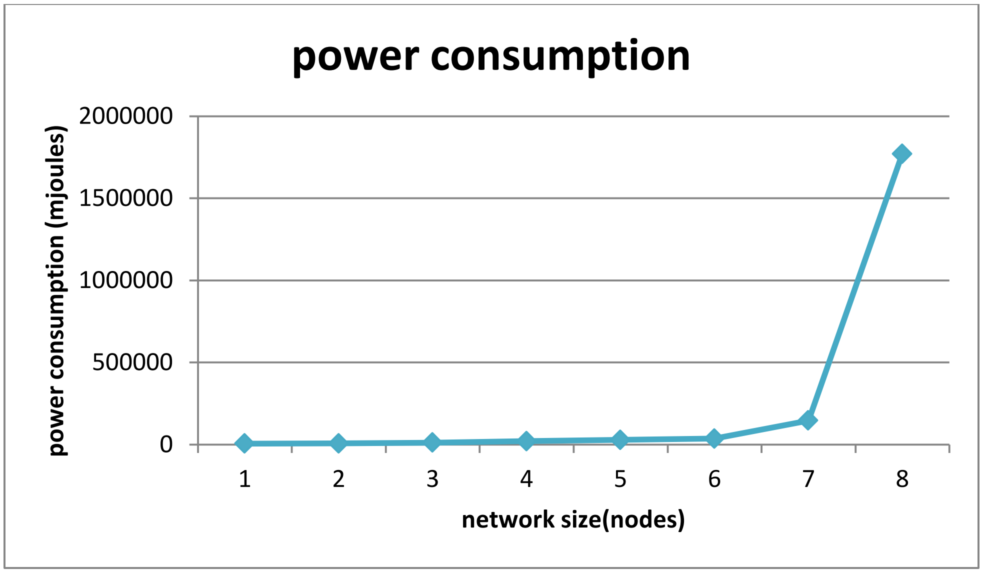

Figure 6: The relationship of power consumption with the size of network

CONCLUSIONS

This study shows that, as many wireless sensors detect the same event and try to forward the data to other nodes, data becomes redundant and degrades the performance of the network by increasing collisions, delay, and energy consumption. Data Aggregation techniques are used in some applications to reduce the redundancy in forwarded packets. In these techniques, packets are aggregated at intermediate nodes and the correlated data is forwarded from one node to another [14].
Also, as sensor nodes are energy constrained, energy efficiency is one of the primary concerns in trying to find suitable protocols for these networks.
To enhance the packet-level reliability and reduce energy consumption, we developed a reliable network topology which incorporates data aggregation using directed diffusion and duplicate suppression techniques. For WSN, many protocols have been proposed that provide reliability and good transmission ranges with low power consumption and we found ZigBee protocol being the best technology to date. It has many advantages which includes its portability, long range transmission (up to 1 km), free frequency bands and scalability and low prices. It is based on IEEE802.15.4 MAC and PHY and have data rate up to 250kbps and provides 16 channels in the unlicensed 2.4GHz band. It is supported with JN5148 wireless microcontroller and modules.
Our simulation results show that node placement and data aggregation techniques improve energy efficiency and the packet forwarding even in large highly dense WSN. However, latency tends to increase under congested scenarios because of increase in collisions, delay, and energy consumption. In general, an increase in latency would affect the performance of the network.
In the future, we would like to extend our research into real time hardware implementation of these Topologies and data aggregation techniques.

REFERENCES

[1] Abhinav Valada, David Kohanbash, George Kantor. Design and Development of a Wireless Sensor Network System for Precision Agriculture. Tech. report CMU-RI-TR-10-21, Robotics Institute Carnegie Mellon University Pittsburgh Pennsylvania, June 2010

[2] Adekeyede A. Elusoji, A. U. Rufai, An overview of smart sensor technology. Academic Leadership Online Journal, vol. 9, issue 2, Mar 21 2011

[3] Amitabha Ghosh, Algorithmic Aspects of Throughput-Delay Performance ForFast Data Collection in Wireless Sensor Networks, PhD thesis, USC Graduate School University Of Southern California, August 2010

[4] Chong, Chee-Yee and Srikanta P. Kumar (2008). "Sensor Networks: Evolution, Opportunities, and Challenges", *Proceedings of the IEEE*, *91*, 8, 1247-1256.

[5] Culler, D.D.Estrin and M.Srivastava (2007). "Overview of Sensor Networks", *Computer*, Washington, DC IEEE Computer Society 40-49.

[6] Hamid Barati, Ali Movaghar, Ali Barati, and Arash azizi mazreah.A Review of Coverage and Routing for Wireless Sensor Networks World Academy of Science, Engineering and Technology 37 2008.13-14

[7] J Balendonk, J Hemming, B A J Van Tuij, L Incrocci, A Pardossi, P Marzialetti, Sensors and Wireless Sensor Networks For Irrigation Management under Deficit Conditions (FLOW AID), 2009.3-5

[8] Jamal N. Al-Karaki, Raza Ul-Mustafa, Ahmed E. Kamal: Data

aggregation and routing in Wireless Sensor Networks: Optimal and heuristic algorithms. Computer Networks 53(7): 945-960 (2009)

[9] K.Ramanan and E.Baburaj, data gathering algorithms for wireless sensor networks: a Survey, international journal of ad hoc, sensor & ubiquitous computing (ijasuc) vol.1, no.4, December 2010doi: 10.5121/ijasuc.2010.1410. 102

[10] Marc Van Lersel and Stephanie Bumett, Using water sensors for efficient irrigation in greenhouse, 2010.4-7

[11] R. Jordan, R. and Abdallah, C.A. (2009). "Wireless communications and networking: an overview," Report, Elect.And Comp. Eng. Dept., Univ. New Mexico.21-26

[12] Reberto, Localization in Mobile Wireless Sensor Networks,World Academy of Science, Engineering and Technology 63 2010.25-32

[13] Sungrae CHO, Proactive Data Filtering Algorithm for Aggregation in Wireless Sensor Networks,IEICE TRANS. COMMUN., VOL.E91–B, NO.3 MARCH 2008.13

[14] U. Monaco, F. Cuomo, T. Melodia, F. Ricciato, M. Borghini, Understanding optimal data gathering in the energy and latency domains of a wireless sensor network, Computer Networks 50 (2006) 3564–3584

[15] Vamsi Krishna Venkata Naga Nandanavanam, Energy-Efficient Reliable Sensor-To-Sink

[16] Wei Han, Three-tier wireless sensor network infrastructure for Environmental monitoring Kansas State University Manhattan, Kansas 2011.70-71

[17] ZigBee_PRO_PB v1.2, NXP Laboratories UK Ltd 2010 1-2, http://pdf.directindustry.com/pdf/jennic/product-brief-jn5148-ek010-evaluation-kit/34237-183747.html (accessed 24 Sep 2012)

[18] Zhou Yiming , Xianglong Yang , Wang L, Yibin Ying, A Wireless Design of Low-Cost Irrigation System Using ZigBee Tecchnology. NSWCTC '09 conference, 2009**.**

[19] Feliciano Cayanan, D., Dixon, M. and Zheng, Y. 2008. DEVELOPMENT OF AN AUTOMATED IRRIGATION SYSTEM USING WIRELESS TECHNOLOGY AND ROOT ZONE ENVIRONMENT SENSORS. Acta Hort. (ISHS) 797:167-172 http://www.actahort.org/books/797/797_22.htm

[20] W. Zhang, G. Kantor, and S. Singh Integrated wireless sensor/actuator networks in agricultural applications. 2nd ACM International Conference on Embedded Networked Sensor Systems (SenSys), page 317, Baltimore, Maryland, USA, Nov. 2004.