

ENHANCEMENT OF NETWORK LIFETIME USING NODE BEHAVIOUR MODELLING IN WIRELESS SENSOR NETWORKS

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Abstract

Wireless Sensor Networks are interconnection of sensor nodes that cooperatively work for sensing some physical quantity such as temperature, pressure, radiation, etc. This sensor node senses the data and transmits them to some base station. As sensor nodes are battery driven, an optimal consumption of battery power is necessary so as to enable the network to operate for long duration. This is particularly important as in most of the cases, these networks are deployed in harsh and hostile environments and it is not feasible to replace the batteries frequently. The main goal of data aggregation algorithms is to gather and aggregate data in an energy efficient manner so that network lifetime is enhanced. However, data aggregation comes with a cost of latency or delay in the network, which is critical in the case of Real time wireless sensor network applications. Data aggregation has emerged as a basic approach in WSNs in order to reduce the number of transmissions of sensor nodes, and hence minimizing the overall power consumption in the network. In this paper, an analytical model of wireless sensor network is developed with an aim to extend network lifetime. The proposed technique inculcates selfishness in the nodes based on an objective function which calculates the data duplicity / similarity and the residual battery life of the node. This results in energy hole alleviation, thus enhancing the network lifetime. Proposed work extends the techniques proposed by Naeem Jan et. al., through complementing it with the redundancy removal and residual battery life computation. The overall performance of the proposed methods is evaluated using MATLAB simulator in terms of aggregation, average packet drops, transmission cost and network lifetime. Finally, simulation results establish the validity and efficiency of the approach.

Keyword: Wireless sensor network, Data aggregation, Selfishness, Dynamic Routing

1. INTRODUCTION

1.1 Introduction

Sensor nodes are the collection of nodes which forms a network that enable computing system to sense some specific physical property that belongs to region and take corresponding action [1]. These are deployed in vast variety of regions that includes the following;

1. Fire sensors at commercial buildings
2. Body temperature / heart-beat sensors at ICU
3. Radiation sensors at Nuclear Reactors

The above list is indicative, yet far from complete. In these applications, the data collected by sensor nodes from their physical environment need to be assembled at a host computer or data sink for further analysis. The simplest design of a WSN consists of a collection of sensor nodes (motes) which senses the data and transmits it to the central node called sink node. Typically, the sensor nodes are resource constrained in terms of computing resources and battery power and the sink node is resourceful in terms of both. In most of the deployments of the sensor networks, the data sensed by the nodes is not directly

transmitted to the sink node. The intermediate sensor node acts as data aggregators and routers [2] which receives the data from some sensor nodes (which are generally far from sink node) and transmits to the sink node or some other nodes to pass on the data towards the sink node.

Typically, an aggregate (or summarized) value is computed at the data sink by applying the corresponding aggregate function, e.g., MAX, COUNT, AVERAGE or MEDIAN to the collected data [2]. In large sensor networks, computing aggregates in-network, i.e., combining partial results at intermediate nodes during message routing, significantly reduces the amount of communication and hence the energy consumed. An approach used by several data acquisition systems for sensor networks is to construct a spanning tree rooted at the data sink, and then perform in-network aggregation along the tree. Partial results propagate level-by-level up the tree [3,4], with each node awaiting messages from all its children before sending a new partial result to its parent. Researchers have designed several energy-efficient algorithms for computing aggregates using the tree-based approach. Tree-based aggregation approaches [5,6], however, are not robust to communication losses which result from node and transmission failures and are relatively common in sensor networks. Nevertheless, data aggregation provides a way to increase network lifetime of nodes by reducing the number of transmitted data packets, possibly at the cost of latency. With the advent of high functionality semiconductor IC's, any WSN node can be programmed to implement aggregation function at relatively no additional cost. This leads to considerable increase in network lifetime. Moreover, protocols such as LEACH (Low Energy Adaptive Clustering Hierarchy) ensure evenly dissipation of energy in cluster nodes thereby ensuring mechanisms to increase network life at higher layers.

1.2 Problem Statement

Data aggregation is a critical task that needs to be done in most efficient way in the sensor networks. The nodes senses the data, then forwards the data to the next hop sensor node where the aggregation takes place consequently, the aggregated data is forwarded to the sink node or the next hop sensor node in the path to the sink. One interpretation of this scenario is this that the sensor nodes which are close to the sink node rapidly runs out of the battery as these needs to send a large amount of data to the sink. The other fact is this that if the sensor nodes are equipped with an antenna with a transmission range that is sufficiently higher to encompass a large number of nodes in the proximity of the sink nodes, then there are a large number of nodes that are able to transmit the data directly to the sink node without the need of intermediate router nodes. This reduces the overhead of the near proximity nodes. However, increasing the transmission range results in increased battery consumption leading to rapid depletion of battery in all the nodes. Thus an optimum transmission range must be chosen given a network description and density of the nodes.

The second aspect of this work is to include the selfishness in the sensor nodes. Selfishness is the property by virtue of which the nodes in the network saves the battery life. When the residual battery in some sensor node falls beyond a certain threshold, the node enters into a mode to save the battery power. In this stage, the node restrict itself to play the role of a router. However, it senses the data and forwards to the base station but does not act as router to cooperate the other nodes for data forwarding.

In this paper, a technique is developed to provide the decision making in the node to control the selfishness behavior. Simulation of the results shows that choosing a suitable objective function for selfishness behavior results in significant increase in network lifetime. Furthermore, the proposed selfishness policy includes the dropping

of only redundant data packets thereby leading to no effective data loss due to packet dropping.

The analytical model being developed is based on 250kbps, 2.4 GHz networks with AtMega128 microcontrollers [7] with TinyOS. This cost function enable to set up threshold values for data aggregation and latency tradeoffs so as to find suitable design of WSN for specific network lifetime and latency requirements of the deployment.

1.3 Network Model

In this work, a tree based model for data aggregation is considered. The duty cycle of the sensing of the data is maintained by the sink computer. The nodes sleep for most of the time, then wakes up and senses the data, followed by intermediate computation and then data transmission. The node then sleeps again. This process is repeated for the entire duration of the life cycle of the node. The ratio of the wake up to sleep time is called the duty cycle of the node. Typically, low duty cycles are maintained to enhance network lifetime. This mechanism is implemented at MAC sub-layer where MAC super-frame structure is defined. It is assumed that the nodes are stationary and hence the path from the node to the sink node, once chosen is not changed. Also, all data transmission and intermediate computation occurs at the end of duty cycle. Thus, the network operates synchronously. The node regularly senses the data and transmits to the sink or the router node. This is done irrespective if the sensed data is critical or not. Aggregation is done based on tree topology and consequently, the aggregated data reaches the sink node. However, the nodes are not perfect and may malfunction. Also, occasional erroneous computation may be possible due to hardware faults or compromised nodes and thus, care must be taken to account for all these issues.

2. RESEARCH APPROACH

Mathematical model of WSN node based on ATmega microcontroller and TinyOS [8] operating system is being developed. Power dissipation is computed using first order radio energy dissipation model. Objective function is computed considering the fact that most of the data packets consists of redundant data and thus, can be dropped. However, if the reading of the sensed data is changed, then the data needs to be delivered to the sink node. Simulation of the model is done using MATLAB, and simulation results are presented along with the analytical results.

3. PROPOSED WORK

3.1 The Network Model

The proposed work assumes the following network model which is applicable to a large subset of wireless sensor network deployments:

1. There is a total of n sensor nodes that are distributed over a geographical region R . Also, the distribution of the nodes is uneven over the area.
2. Each node has transmission range T . Also, T is considerably smaller than the radius of the region and hence, not all nodes are capable of directly sending the data to the sink node. These nodes takes the assistance of other nodes, which are used as routers to transmit the data to the sink node.
3. Nodes over the region R are grouped into Clusters. Each sensor node belongs to exactly one of the clusters. Each cluster has a Cluster Head (CH) which has the responsibility of receiving the data from the nodes and transferring it to the sink node, either directly or through routers.
4. The cluster head is elected periodically through some leader-election algorithm, such as LEACH or its variant.

5. The Cluster Head is a Full Function Device (FFD) and performs the task of data aggregation. This aggregated data is then transmitted to the sink node.
6. The data aggregation and transmission in sensor nodes follows the first order radio energy dissipation model.
7. The data sensing, data transmission, data aggregation and further transmission follows some pre-specified schedule and the devices work synchronously with each other in lieu with the duty cycle.
8. The sink node is located at the center of the region R

In multi-hop transmission, two conclusions can be drawn on the basis of network's fundamental nature:

1. The traffic of the transmitted data is mainly located at the first radius from the sink node. This is because nodes located in the proximity of this curve receives data from the other far off nodes and transmit the same to the sink node. Thus, these are the nodes that exhausts their energy much more rapidly as compared to the nodes that are located at the far boundary of the network.
2. As the transmission range increases, more nodes are capable of transmitting

the data directly to the sink node. Thus, the load on the inner circle node decreases and at the same time, increases on the outer nodes. Moreover, the increase in the transmission range of the nodes leads to much more battery consumption as compared to the nodes with less transmission range. Moreover, the size of the data decreases when the transmission range increases, and increases when the transmission range decreases.

Thus, it can be concluded that energy consumption is mainly dependent on data size and the transmission range.

The prime focus of this work is to balance the energy distribution between all the nodes of the network so that evenly consumption of the energy in all the nodes leads to prolonged battery life.

3.2 First Order Radio Energy Dissipation Model

The first order radio energy dissipation model is most important to consider in view of the computation of other QoS parameters for the network model specified above. The model equations are described for transmission and reception as well as for the intermediate data processing or compression. A simple model of transmission and reception system is illustrated in figure 3.1

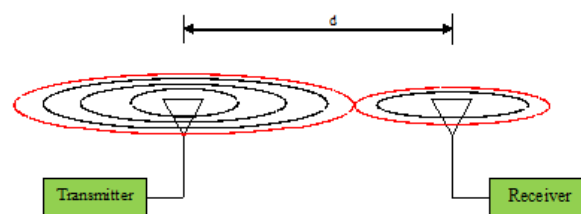


Fig. 3.1 A typical Transmitter and Receiver System

It is important to note that the two devices shown above are able to communicate with each other if the transmission range of the antenna is greater than d . Also, the signal strength of the transmitting antenna at a distance d must be sufficient for its detection at the receiver located at that point.

The energy spent in transmission of single bit to d distance is given by:

$$etx(d) = e_{t1} + e_{d1}d^n$$

where e_{t1} is the energy dissipated per bit in the transmitter circuitry and $e_{d1}d^n$ is the energy dissipated for transmission of a single bit over a distance d , n being the path loss exponent (usually $2.0 \leq n \leq 4.0$). For transmission in air near ground level, $n \sim 2$.

The energy consumption per bit for the successful reception of data is

$$erx = e_{r1}$$

In the simulation model considered, $e_{t1} = e_{r1} = 50\text{nJ/bit}$, and $e_{d1} = 100\text{pJ/bit/m}^2$.

Consider transmission and processing of 10kb data using the dissipation model given above. The energy consumption in processing of this data at each of transmission and reception end consumes

$$E_t = E_r = 10 * 1024 * 50 * 10^{-9} \\ = 0.000512 \text{ Joules}$$

However, for transmission of the same data over a distance of 50 mtr, the radio circuit consumes

$$E_d = 10 * 1024 * 100 * 10^{-12} * 50 * 50 \\ = 0.00256 \text{ Joules}$$

It is clear that the energy spent in amplifier circuit alone for transmission of the 10kb data over 50 mtr is 5 times as compared to energy spent in processing the same data. Thus, for prolonged network lifetime, it is important to do maximum in-network data processing.

Consider the model of the network illustrated in the fig 3.2

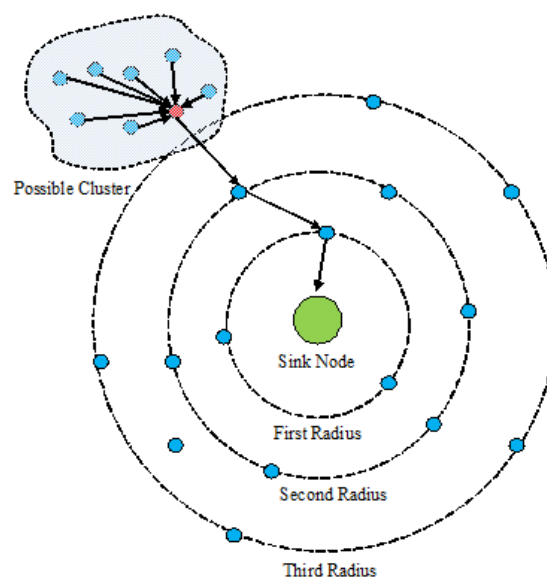


Fig 3.2 Data Transmission Illustration of WSN

In the above figure, the cluster shown has a number of sensor nodes (shown in blue color) and a cluster head (CH), shown in red color. The sink is located at the center. The Cluster Head aggregates the data from the nodes in the cluster and transmits the data to the sink nodes, possibly through multi-hop data transmission using one or more intermediate sensor nodes which may be a part of some other cluster. The concentric circles shown in the figure corresponds to the transmission range of the nodes. Nodes in the proximity of border of one circle can communicate with the nodes of the adjacent circle.

3.3 Proposed Balanced Energy Consumption Algorithm (BECA)

When the network is deployed, each node is unaware of the nodes in its surroundings. The initial configuration of the network involves the exchanging of a hello message through which each of the node gets aware of information of the sink node, the network id's of the nodes in its surroundings, the received signal strength, residual energy of the neighboring nodes, etc.

The proposed Balanced Energy Consumption Algorithm works as follows:

1. In each circle boundary, except the outermost circle, the nodes which belongs to the proximity of the boundary works as data aggregators. This means that they aggregate the data received from outer nodes with the data generated by them and passes this aggregated data to node near the adjacent closer proximity with the sink node.
2. At each boundary, there are nodes which are heavily burdened as well as the nodes that experience light traffic. The sensor node which participates more in the data transmission consumes energy quickly.

3. Each node (or Cluster Head) in the outer radius computes the residual battery of all the nodes in the inner circle which are in its transmission range. It then performs the following computation:

$$E_{avg} = \sum_{i=1}^{n_i} (E_i)/n_i$$

Here, n_i is the number of nodes in the proximity of the node (CH), and E_i is the residual energy in the i^{th} node.

4. Initially the nodes which have residual energy greater than the average energy are chosen as the next hop nodes for the data transmission. The node is used as next hop router till the residual energy level of the node falls below E_{avg} . At that time, another computation is performed for E_{avg} and node which has highest energy is selected.
5. Let E_T denotes a pre-specified critical energy level called the threshold energy level E_T . Any node with the residual battery life E_T is programmed to enter into SELFISH state. At this state, the node, the behavior of the node follows one of the following two roles:
 - a. The node stops generating its own data and will work only as router.
 - b. The node refuses to work as router and will only generate and transmits its own data.
6. When a pre-specified fraction of all the possible hop routers for a node enters into the selfishness state, the network is reconfigured to reduce the packet size in the MAC layer, thus, leading to less battery consumption per transmission in the nodes.

7. After the reconfiguration of the MAC layer payload data, the process is repeated as in step 4.

It is important to note the two aspects as the node enters into the selfishness state. The data traffic may be low for a long time with short burst in traffic. The traffic is multi-hop and usually goes towards the base station. At each node there is a contention between traffic originating at that node and the data being routed through it. This is because each node doubles as a data generator and router. The probability of corruption and contention at every hop is higher for the nodes residing farther from base station. Since energy is invested in routing the packets, the more time a packet spends in the network the more cost gets associated in dropping the packet. Thus, higher priority must be given to routed traffic than originating traffic.

Section 4 analyzes the proposed algorithm against the case where no energy balancing technique is present, as well the against the BECHA (Balanced Energy Consumption and Hole Alleviating Algorithm) for various network parameters under varying settings for selfishness energy levels.

4. ANALYSIS OF PROPOSED WORK

4.1 Network lifetime in Random Router Selection

For simulation purpose, the parameters used correspond to TinyOS on ATmega128L microcontroller. Consider the following typical values of parameter:

TABLE 4.1 PARAMETER SPECIFICATIONS OF VALUES OF VARIABLES IN THE ANALYTICAL ANALYSIS

Parameter Symbol and Description.	Value
Data Rate, Frequency Band	250kbps, 2.4 GHz
Transmission Range	10m/20m
N; Number of Nodes in the Network, considering all as the active nodes	[10:500]
C; Number of Clusters in the Network	[0, 0.05]; Vector ranging from 0 to 0.05 percent of the number of nodes in the cluster.
λ ; Mean number of Packets transmitted by each node per unit time	[1,100]. Max. achievable data rate assumed to be 110 kbps. Also considering fragmentation at the link layer for large packet sizes.
R; Bits per Packet	114 bytes TinyOS Specification
e_{t1} ; energy dissipation per bit in transmitter circuitry before transmission	50nJ/bit
e_{d1} ; energy dissipation per bit in sending a bit over d distance.	10pJ/bit/m ²
e_{r1} ; energy dissipation per bit in receiver circuitry.	50nJ/bit
J; Energy Consumption of ATmega128L per CPU cycle. Being 8 bit microcontroller, it processes 8 bits per unit time.	100nJ/bit
Battery Consideration	1.5Volt, 3000 mAh (Duracell)
Ampere Rating of ZigBee Temperature / Humidity Sensor	55mA

The sensor mote used for this simulation is DigiXBee humidity sensor.



Fig 4.1 DigiXBee humidity sensor [Courtesy: AliExpress.com]

With continuous sensing without sleep intervals (Hibernation Period), the single device can work for a period of $3000\text{mAh}/1.5\text{mA} = 2000\text{Hrs}$. This is equivalent to about 84 days or about 2.7

months. With the duty cycles involving sleep and wake up time the achievable operating time for this humidity sensor with the specified batteries is given as follows:

TABLE 4.1 BATTERY LIFE OF XBEE MOTES

Operation Specification	Battery Life Estimate
1 Read Operation per 30 Sec	1.5 Years
1 Read Operation per minute	2.5 Years
1 Read Operation per hour	6 Years

The above assumptions are based on Cyclic sleep enabled with single transmit per wake cycle; Ambient temperature at 21°C .

Thus, the initial energy level of the node in joule is:

$I^2 \cdot R \cdot t = V \cdot I \cdot t = 1.5 \cdot 1.5 \cdot 10^{-3} \cdot 2000 \cdot 60 \cdot 60 = 16200$ Joules. This is the typical energy level of lithium ion battery and is consistent with the same.

Considering a set of 50 nodes over a region each with certain transmission range. Let the initial battery life of the nodes be 11050 Joules []. The initial battery level of the nodes and the battery status of the nodes at the point when the first node runs out of the battery is shown in figure 4.1 and 4.2.

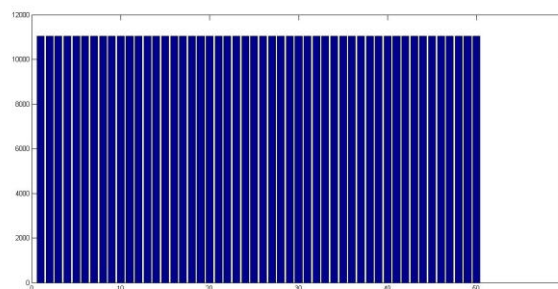


Fig 4.1 Initial battery level of the nodes (=11050 Joules) [].

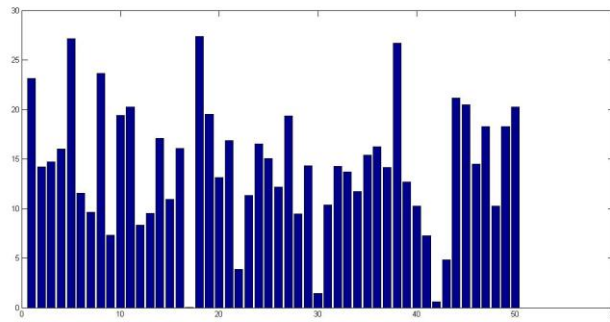


Fig 4.2 Battery level of the nodes at the onset of node dying.5% of all the nodes also working as routers. Total read operations = 235938

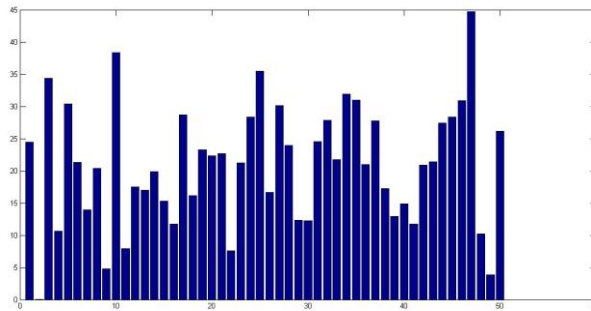


Fig 4.3 Battery level of the nodes at the onset of node dying.10% of all the nodes also working as routers. Total read operations = 220123

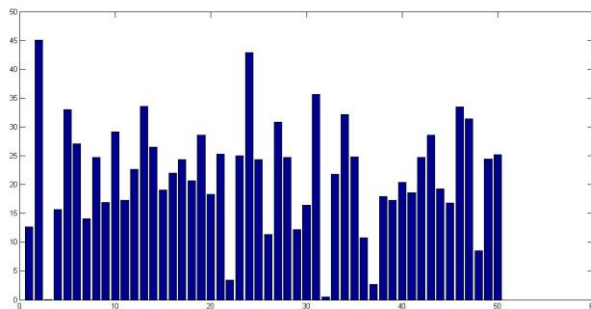


Fig 4.4 Battery level of the nodes at the onset of node dying.20% of all the nodes also working as routers. Total read operations = 188664

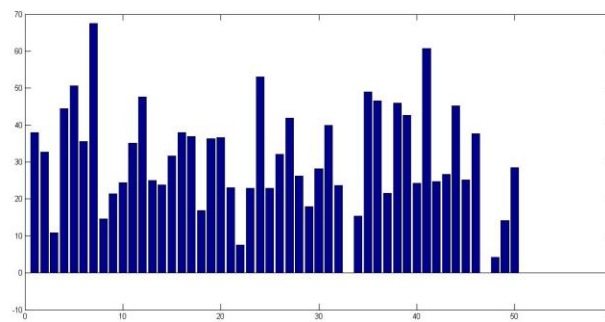


Fig 4.5 Battery level of the nodes at the onset of node dying.50% of all the nodes also working as routers. Total read operations = 131960

The following table deduce the network lifetime for the set of graphs depicted above.

TABLE 4.2 NETWORK LIFETIME (RANDOM ROUTER SELECTION TOPOLOGY)

# Read Operations	Frequency	Network Life (in years)
235938	Once every 30 seconds	0.22756366
220123	Once every 30 seconds	0.21230999
188664	Once every 30 seconds	0.18196759
131960	Once every 30 seconds	0.12727623
235938	Once every 60 seconds	0.45512731
220123	Once every 60 seconds	0.42461998
188664	Once every 60 seconds	0.36393519
131960	Once every 60 seconds	0.25455247

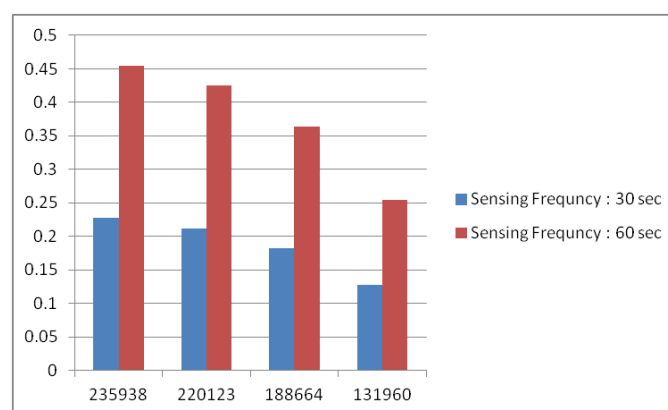


Fig 4.6 Network Lifetime: The vertical Axis shows the network lifetime in Years. The horizontal axis shows total read operations, corresponding to 5,10,20 and 50 percent nodes as routers respectively. (Single AA Lithium Ion Battery)

It is important to note that the following parameter values deduce are for random node selection as router. In general, the sensor networks, in simplest setting, adopt a static

routing configuration in which the nodes near the sink faces heavy load, irrespective of their residual battery life. In such a situation, these nodes die much early as compared to the nodes

at the boundary of the region. The values depicted above, are therefore the best case values of the parameters that are compared for network quality of service.

4.2 Network Configuration with Preferable Router Selection

The static network configuration is depicted as shown in figure 4.7 in random topology.

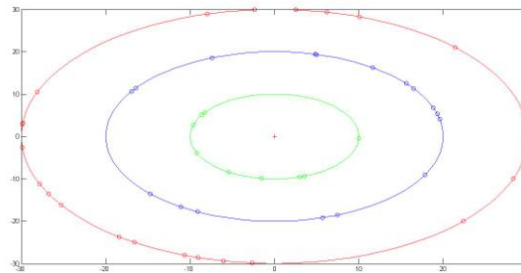


Fig 4.7 Static Network configuration.

In the above figure, the sink is shown in the middle of the figure. There are a total of 50 nodes arranged proportionally in three concentric circles in the proportion of the circumference. The innermost sensor nodes which are closest to the sink are shown in green color. The middle nodes are shown in blue color and the outermost nodes are shown in red color. The concentric circles shown above have a radius of 10, 20 and 30 mtr respectively, and the transmission range of each node is ~20 mtrs.

Thus, the outermost nodes transmit the sensed data to the nodes at the middle circle and the middle nodes transmit the data sensed by them, as well as the data transferred to them by the outermost nodes to the innermost nodes. The innermost nodes transmit the data sensed by them as well as the data transferred to them by the middle layer to the sink node. The possible communication paths of this 50 node configuration are shown in figure 4.8.

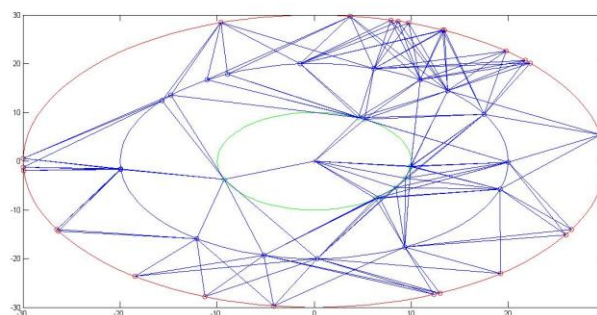


Fig 4.8 Possible transmission paths between the nodes. Transmission Range ~20mtrs.

Considering the shortest paths that the nodes adopts to transmit the sensed data to the next hop

node, the transmission paths in the network shown are depicted as shown in the figure 4.9.

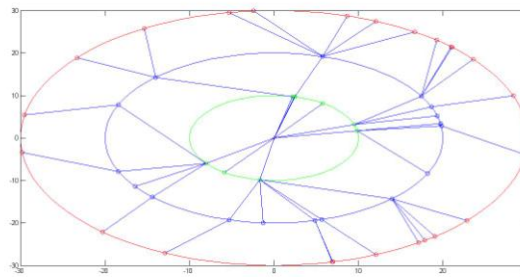


Fig 4.9 Shortest Possible transmission paths between the nodes.

With this network configuration, the nodes statically transmit the sensed data to the node closest to it in the next closer circle towards the sink node.

For a configuration with 500 nodes, this data transmission configuration would be as depicted in the figure 4.10.

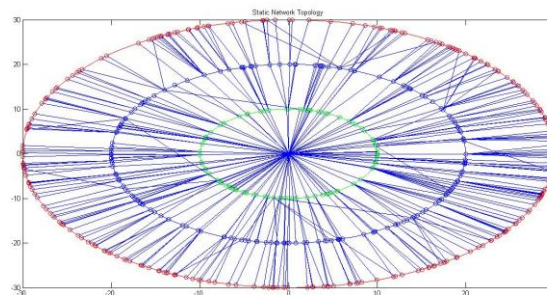


Fig 4.10. Network configuration with 500 nodes

It is clear that a large number of nodes in the inner circle would act as routers under heavy burden of data transmission from the layers outside the periphery and thus soon runs out of

the battery life. Assuming one read operation in 30 seconds for XBee motes for sensing Humidity, the battery life corresponds to the table 4.3.

TABLE 4.3 NETWORK LIFETIME (One Read Operation per 30 seconds, 3 Layers)

# Nodes	Number of Cycles
50	112010
100	92456
150	82456
200	78423
250	54789
300	46798
350	39873
400	31278

The network lifetime in terms of number of rounds (each round of 30 sec), in static

configuration where the sensing and transmitting nodes are unaware of residual battery life, is shown in figure 4.11

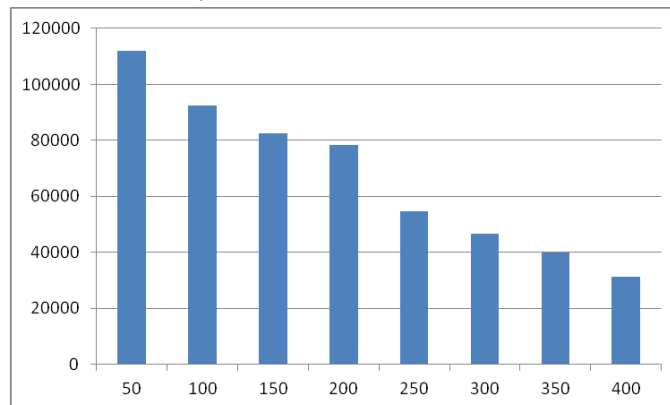


Fig 4.11 Network Lifetime. Horizontal axis shows the number of nodes and the vertical axis show the number of rounds.

4.3 Network Lifetime: Balanced Energy Consumption Algorithm (BECA)

In the proposed BECA technique, the node is programmed to enter into selfish state provided that the residual battery in the node falls below a threshold. At this stage, the node enters in either of the two states:

1. The node stops generating its own data and will work only as router.
2. The node refuses to work as router and will only generate and transmits its own data.

The simulation results are performed with the assumption that at this stage, 50 percent of the

nodes of any layer performs (1) and the rest fifty percent performs (2), among those who have battery level below threshold. The initial energy in each of the nodes is considered to be 11050 Joules.

Table 4.4 corresponds to the network lifetime achieved through BECA and Dynamic routing proposed by Naeem Jan et. al. [33] under similar settings. The latter provides dynamic routing change when the energy level of the router falls below a threshold. However, the proposed BECA, apart from providing dynamic routing, introduces selfishness in the nodes in which the nodes enter in one of the two states described above.

TABLE 4.4 NETWORK LIFETIME:- BECA Vs [33]

# Nodes	# Rounds	# Rounds [33]
50	101003	87283
100	102875	92456
150	107452	97227
200	119845	109341
250	128765	113843
300	132986	119221
350	139453	124781
400	145005	131847

The pictorial illustration of table 4.4 is shown in the figure 4.12.

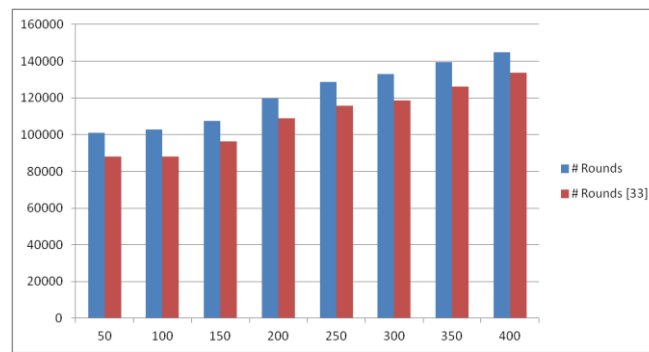


Fig 4.12 Network lifetime with proposed BECA versus [33].

It is clearly evident that the proposed Balanced Energy Consumption algorithm gives much more network lifetime and that grows with the number of nodes. This is because with the increasing number of nodes, there are vital options available for any outer layer nodes to choose from the inner layers, thereby increasing the network lifetime. However, it is important to note that the increased network lifetime as compared to Naemet. al. comes from the fact that at the critical residual battery level, 50 percent of the nodes stops the primary function of data sensing, rather acts only as routers to transfer data transmitted by the outermost nodes to the sink node. Section 5 gives an insight of the results deduced drawing the conclusion and also gives the scope for the future work.

5. CONCLUSION

This paper provides a detailed review of the balanced energy consumption techniques existed in the literature for enhancing the network lifetime in wireless sensor networks. As stated previously, the energy is a scarce resource in WSN and its consumption needs to be balanced in the entire network. In most of the cases of static network deployment, a set of nodes only senses the data and transmits to the nearby nodes. Also, there is another set of nodes that, in addition to sensing the data, also aggregates the data received from other nodes and transmit the same to the sink node or to some other nodes in the network. This latter class of nodes comprises of a subset of such nodes that are overburdened

with the task of data aggregation, and thus, these nodes run out of the battery far more earlier as compared to the other nodes that only senses and transmits the sensed data.

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