

EFFECT OF INCREASING NODE DENSITY ON REINFORCEMENT LEARNING BASED ENERGY PRESERVATION ROUTING ALGORITHM FOR WIRELESS SENSOR NETWORK

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ABSTRACT

A wireless sensor network (WSN) is a network consisting of miniaturized smart sensors communicating the information gathered or collected from a monitored environment via a wireless link. The sensors are capable of sensing the events within their environment, process the data, and transmit the data to the base station (BS). The entire processing of data and subsequent transmission to BS requires high energy consumption. The operation of WSN is limited by repeated dead nodes, which results in energy depletion. Hence, to prolong the life-span of the network, several routing protocols have been developed. In this paper, the effect of increasing node density on cluster based energy-efficient routing protocol based on reinforcement learning (RL) in wireless sensor network was analyzed. Simulations were conducted in MATLAB. When the number of sensor nodes was 50, the number of alive nodes after 5000 rounds was 3. However, as the number of nodes was increased to 90, it was observed that there were 28 nodes after 5000 rounds. Conversely, the energy consumed after 5000 rounds was 0.000871 J for 50 nodes and 0.007184 J for 90 nodes. Generally, increasing number of nodes in sensor network can extend the network lifespan, but this will cause an increase in the amount of the energy consumed.

Keywords: *Node density, Reinforcement learning, Routing protocol, Wireless Sensor Network*

1. INTRODUCTION

A typical wireless sensor network (WSN) can have an installed capacity of thousands of sensor nodes, and these nodes are generally resource constrained. This means the nodes are expected to use little power as possible from the available sufficient computational and transmit power in order to accomplish their function. This is because the nodes depend on the energy of a battery for power and are required to perform for long periods without being replaced. In addition, a node in a sensor network is characterised by limited processing speed, communication bandwidth, and storage capacity (Muoghalu et al., 2022). After a WSN has been successfully installed, the sensor nodes are responsible for self-organizing an appropriate continuous network connection for multi-hop communication within them (Team Tesca, 2021).

WSN deployment can be random or regular. Random deployment of WSN involves the distribution of sensor nodes in an even manner over the network, whereas in regular deployment, the sensor nodes are positioned in static manner. Moreover, in WSN, nodes can be stationary or mobile and deployment in their environment can be randomly or by a way of appropriate mechanism of deployment (Kashaf et al., 2012). While being deployed, WSN needs to be energy efficient and secured.

In ideal case, a typical WSN should be easily improved upon or expanded, energy efficient, smart and being able to be designed or shaped with a view to specific applications or uses, reliable, prolonged, very quick to respond, and cost-effective installation and maintenance. All the same, considering the available limited resources, the purposes are positive. Unlike other ad-hoc networks, WSNs are basically notable due to the limited sensor nodes capabilities. For example, a sensor node may have a typical processor with clock rate of 8 to 400 MHz (Saleem et al., 2011). The memory of a sensor node in WSN may be in the range of 32 to 512 kb that may by external means further extended to few Megabytes (Mb). There is battery that powers a sensor node, which is one of the most critical components. This battery, in most cases, is not rechargeable or

impossible to recharge when node is deployed. Hence, each sensor node in the network places an energy cost or burden for every action carried out, which gradually reduces power of sensor node. Therefore, the prime requirement of each sensor node in a WSN is to maintain energy-efficient operation. However, achieving the ideal characteristics of a WSN with such a limited hardware resource is a very difficult task if not unfeasible (Saleem et al., 2011).

Due to power consumption resulting in energy degradation that takes place during sensing or gathering of information including that of transmission and reception by sensor nodes in WSN, many routing protocols or techniques such as Stable Election Protocol (SEP), Low Energy Adaptive Clustering Hierarchy (LEACH), Threshold Sensitive Energy Efficient sensor Network protocol (TEEN), Enhanced Stable Election Protocol (ESEP), Stable Election Protocol (SEP), and Threshold-sensitive Stable Election Protocol (TSEP) have been implemented. Besides the use evolutionary algorithm such Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), intelligent schemes such as fuzzy logic system and PSO/ACO enhanced fuzzy logic have become recently common including the application of machine learning algorithm such as reinforcement learning (RL). These techniques have been designed to provide of energy-efficient operation in WSN. This paper presents the performance analysis of energy conservation routing scheme based on RL under varying node density.

2. BASIC CONCEPT OF WSN DESIGN

This section described the basic terms in the design of WSN considering known framework in literature. The challenge associated with designing and consequent selection routing scheme, and the effect of increasing population of nodes in WSN.

2.1 Routing Protocol Design

A critical and very significant issue in the deployment of WSN is the selection of the optimal routing protocol due to the limited resources that is available. Hence, many factors must be considered in to have successful packet delivery from source node to destination node (Bazzi et al., 2015). Hence in the design of routing protocols, several outstanding factors needs to be taken in to consideration has briefly discussed as follows.

A. Energy Consumption

The lifespan of a sensor is determined by the length of time the stored energy in its battery is exhausted. Considering the size of the sensor node, the battery energy is usually limited and small (Heinzelman et al., 2000). Therefore, this is seen as the major challenge in WSN routing protocol design since it is aimed at the possibility of using less energy by nodes in transmitting data (Bazzi et al., 2015). For instance, for more energy to efficiently preserved in a node battery, the aggregation of data and its transmission are carried via hierarchical routing cluster head (CH) (Ramesh and Kruba, 2015).

B. Scalability

In this case, the designer of WSN protocol takes into account the possibility of the declining performance in the communication system due increase in node population. Generally, the term scalability means that there will be communication system performance will degrade as more nodes are added to the network. The node density in WSN can range from some tens to hundreds or even thousands per area. This means that the number of nodes in a WSN can change. Hence, required of a routing algorithm to be able to hold a good number of nodes for a given environment where nodes are deployed for data gathering, processing and transmitting.

C. Connectivity

Since nodes are densely deployed for a given area of WSN, there is a possibility of separating each node from the other. Therefore, connection between nodes must remain even after some nodes have failed (Muoghalu et al., 2022; Bazi et al., 2015).

D. Cost of Network

It is very important that the total cost of a network is justified given that in WSN there is the possibility of having hundreds or thousands of nodes with the cost of a node taken into account. Consequently, with the overall cost of the network being influenced by the cost of a single, it is appropriate that the cost of each node be reasonable low as possible (Muoghalu et al., 2022).

E. Data Aggregation

Considering the fact that many sensor nodes may generate redundant data, there may be a number of unnecessary traffic in the network. Thus, combining similar data from multiple sensor nodes will aid in reducing the number of transmission (Biradar et al., n.d.).

F. Quality of Service

In routing protocol design of several existing WSNs, the focus has basically been providing energy efficient network without considerable regard to quality of service (QoS) (Saidarao and Sekhar, 2017). In a WSN application, the QoS required may be network lifespan, data reliability, energy efficiency, collaborative-process, and awareness of location (Saidarao and Sekhar, 2017).

G. Node Deployment

The deployment of node in WSN can be random or distributed. The type of node deployment depends on the application of the network and it affects the performance of routing protocol (Muoghalu et al., 2022).

H. Conditions of Operating Environment

The operating environment conditions can be challenging to the performance of the nodes in the network. Hence, nodes that are to be deployed in WSN application are expected to overcome environment conditions because a network of sensors can be configured anywhere including the bottom of oceans for under water sensing, interior parts of machines, biological or chemical contaminated environment, civil or military surveillance etc.

I. Fault Tolerance

During the deployment of nodes in WSN, there is the possibility of some of the nodes failing due to empty battery, environment not being favourable, or physical damage. Nevertheless, the sensor network should not be affected by the failure of a node or some nodes (Bazi et al., 2015). The routing of packet or data must be guaranteed by routing protocol in order that packet can still be transmitted to the base station or sink to avoid loss of data. In some cases, the solution may be data redundancy.

J. Data Latency

This is also considered a very important factor. Data latency is caused by aggregation and multi-hop delays. In addition, some routing protocols create excessive operating costs or computational complexities when implementing their algorithms. These computational difficulties are not appropriate for energy constrained WSN.

3. SYSTEM DESIGN

Figure 1 shows the structure of the system. Cluster member (CM) node senses data and broadcast it to cluster head (CH). The information sensed is transmitted to the sink via CHs. The communication with sink or base station (BS) is centralized within the network area. It is assumed that the BS has no constraint as regards

energy, computation of power, and memory resources. The WSN uses a centralized routing technique in which the sink node is the centralized item.

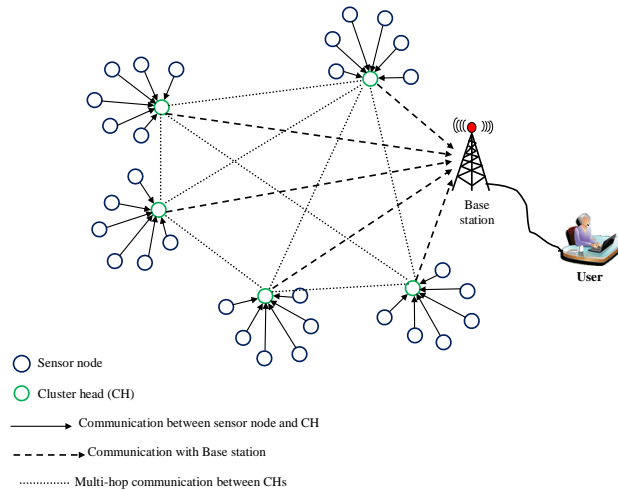


Figure 1: system set-up

Since the proposed system is a heterogeneous WSN, the sensor nodes are assumed to have different energy level. Thus, three levels of heterogeneity are considered as: normal nodes, intermediate nodes, and advance nodes. An illustration of the energy levels of sensor nodes in the network is shown in Figure 2.

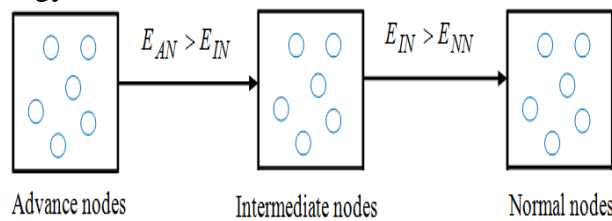


Figure 2: Sensor nodes energy level

The distribution of energy for nodes in the network is illustrated as shown in Figure 2. The arrangement is such that advance nodes have the highest value of energy in the sensor network followed by intermediate nodes and then the normal nodes. Mathematically, given that there are n number of nodes in the network, b number of intermediate nodes, c is factor proportional to number of advanced nodes to total number of nodes n , and then the number of normal nodes in the network is $n - (b + c)$.

The intermediate nodes are equipped with μ times energy more than normal nodes E_o . The energies of the advance nodes and the intermediate nodes are given by (Kashaf et al., 2012):

$$E_{AN} = E_o(1 + \alpha) \tag{1}$$

$$E_{IN} = E_o(1 + \mu), \text{ where } \mu = \frac{\alpha}{2} \tag{2}$$

where E_{AN} is the energy of advanced nodes, E_{IN} is the energy of intermediate nodes, α, μ are constants representing the number of times the energy of the advanced nodes and intermediate nodes are greater than the energy of the normal nodes. Presenting the total energy of each energy level classified in terms of the number of sensors gives:

$$\text{Normal nodes} = n \cdot b(1 + \alpha) \tag{3}$$

$$\text{Intermediate nodes} = nE_o(1 - c - bn) \tag{4}$$

$$\text{Advance nodes} = n \cdot c \cdot E_r(1 + \alpha) \tag{5}$$

Therefore, the total energy of the nodes is given by:

$$E_T = n \cdot E_o (1 + c\alpha + b\mu) \quad (6)$$

The optimal probability (p_{opt}) of nodes to be elected as a CH, taking into consideration the fact that nodes are split on the basis of energy, is calculated as follows.

Optimal probability of node being elected as CH is given by (Kashaf et al., 2012):

$$p_i = \begin{cases} \frac{P_{opt}}{1 + c\alpha + b\mu} & \text{if } s_i \text{ is the normal node} \\ \frac{P_{opt} \cdot (1 + \mu)}{1 + c\alpha + b\mu} & \text{if } s_i \text{ is the intermediate node} \\ \frac{P_{opt} \cdot (1 + \alpha)}{1 + c\alpha + b\mu} & \text{if } s_i \text{ is the advance node} \end{cases} \quad (7)$$

where p_i is the probability of i th node being elected as CH and s_i is the i th sensor node in the network. Now, since the CH election is determined from hop count factor and residual energy used to compute the initial Q-value, the following equations are defined (Mutombo et al., 2021):

$$Q_i = \begin{cases} \frac{1}{N_h}, & \text{if } E_{min} = E_{max} \\ p_i \times \left(\frac{E_o - E_{min}}{E_{max} - E_{min}} \right) + (1 - p_i) \times \frac{1}{N_h}, & \text{if } E_{min} \neq E_{max} \end{cases} \quad (8)$$

$$N_h \cong \frac{D_{link}}{TX_{range}} \quad (9)$$

where Q_i is the initial Q-value, N_h is the hop count, E_o is the residual energy (which is the initial energy level) of sensor node, E_{min} and E_{max} are the minimum energy and maximum energy dissipated, D_{link} is the distance of a sensor node s_i to the BS through an intermediate sensor node s_j (Mutombo et al., 2021), and TX_{range} is the transmission range (Mutombo et al., 2021; Atzori et al., 2010).

Thus the Q-value for learning algorithm is given by (Mutombo et al., 2021):

$$Q_{t+1}(s, a) = (1 - \alpha)Q_t(s, a) + \left(r_{t+1}(s, a) + \gamma \max_a Q(S', a) \right) \quad (10)$$

where Q_t is the initial Q-value or Q-value at time t , Q_{t+1} is the updated Q-value, α is the rate of learning (whose value is usually taken as 1 to speed up the process of learning), $r_{t+1}(s, a)$ is the immediate reward, $\max_a Q(S', a)$ is the highest course of action used to optimized the reward, S' is a maximum state which the course of action or policy ends up and γ is the discount factor (which varies between 0 and 1).

The parameters for the simulation are shown in Table 1.

Table 1 Simulation Parameters

Definition	Symbol	Value
Sensor network area	A	100 × 100 m ²
Coordinate location of base station (BS)	(x, y)	(50, 50)m
Electronic energy	E_{elect}	50 × 10 ⁻⁹ J/bit
Data aggregation energy	E_{DA}	5 × 10 ⁻⁹ J/bit/message
Initial Energy of sensor node	E_o	0.5 J
Amplifier energy	E_{amp}	0.0013 × 10 ⁻¹² J/bit/m ⁴
Number of sensor nodes	n	[50-90]
Packet size	k	4000 bits
Transmission range	r	20 m
Speed rate	α	1
Discount factor	γ	Varies between 0 and 1
Energy level factor	c	0.1

4. RESULTS AND DISCUSSION

In this section, simulations were conducted for the heterogeneous WSN in MATLAB for the purpose of evaluating the performance of the protocol in terms of varying number of node density in the network. It should be noted that the network field and the coordinate of the base station remains the same irrespective of the variation in the number of sensor nodes in the network. The number of nodes has been varied from 50, 60, 70, 80, and 90. Figures 3 to 5 show the simulation curves for each scenario in terms of operating nodes, dead nodes and energy consumed. The numerical analysis for each case considered is shown in Tables 2 to 4.

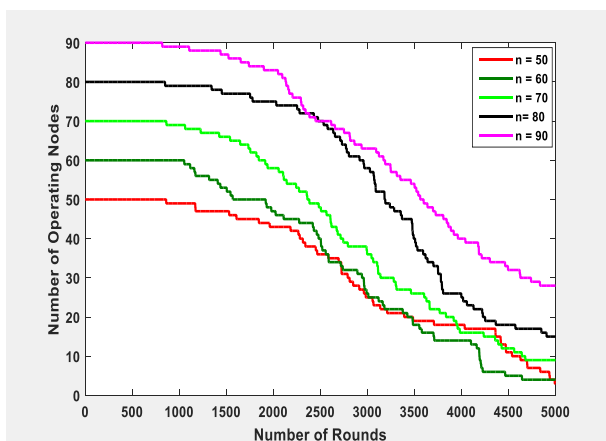


Figure 3: Operating nodes against rounds (for varying nodes)

Figure 3 shows the evaluation of the protocol in terms of operating nodes against the number of rounds for varying number sensor nodes. The numerical analysis in Table 2 revealed that when the sensor nodes were 50, only 3 nodes remain after 5000 rounds. However, in the case of 90 nodes, it was observed that there were 28 nodes still operational after 5000 rounds as shown in Table 4.7. Hence, the simulation results have shown that as the number of node increases (i.e. increase in node density) results in prolonging of the lifespan of the network.

Table 2 Numerical analysis of operational nodes per rounds (different n)

Number of nodes (n)	Rounds	Operational nodes
50	5000	3
60	5000	4
70	5000	9
80	5000	15
90	5000	28

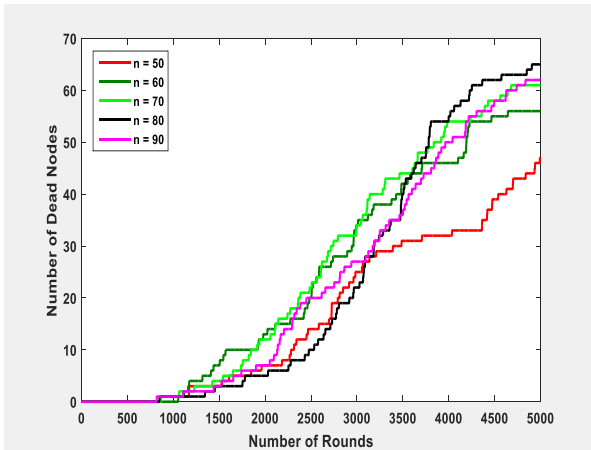


Figure 4: Dead nodes per rounds (different n)

Table 3 Numerical analysis of dead nodes per rounds (different n)

Number of nodes (n)	Rounds	Dead nodes
50	5000	47
60	5000	56
70	5000	61
80	5000	65
90	5000	62

Figure 4 is the evaluation of dead nodes against the number of rounds for different node density in the network. The simulation analysis as numerically shown in Table 3 indicates that when 50 nodes were deployed, 47 of the nodes died after 5000 rounds of sensing operations. On the other hand, when the sensor nodes were increased to 90, the number of dead nodes after 5000 rounds was 62 (i.e. 28 alive). This means that with the number of nodes increased, there is chance of more nodes being alive and the network life prolonged since there is sufficient sensor node to sustain the operation of the WSN.

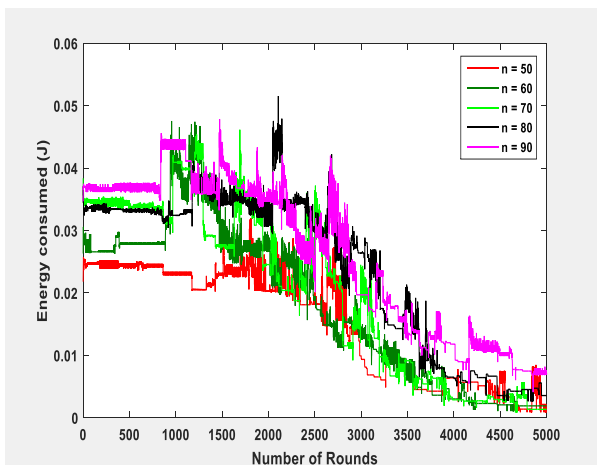


Figure 5: Energy consumed per rounds (for varying nodes)

Table 4 Numerical analysis of energy consumed per rounds (different n)

Number of nodes (n)	Rounds	Energy consumed (J)
50	5000	0.000871
60	5000	0.001336
70	5000	0.001894
80	5000	0.003546
90	5000	0.007184

The evaluation of the energy consumed per rounds under the condition of varying nodes density or population at a fixed network field is shown in Fig 5. The simulation curves were analyzed and presented numerically as shown in Table 4. The analysis shows that as the population of the nodes increases, the energy consumed increases. Thus, looking at Table 4, when the number of nodes was 50, the energy consumed after 5000 rounds was 0.000871 J. However, with the node population or density equal to 90, the energy consumed after 5000 rounds was 0.007184.

5. CONCLUSION

The performance of the proposed scheme was also evaluated for network lifespan and energy efficiency considering the effect of increasing sensor node density. In this case, different number of sensor nodes for a fixed network field was considered. It was observed that the more the sensor nodes the possibility of the

network lifespan being extended. For instance, when the number of sensor nodes was 50, the number of alive nodes after 5000 rounds was 3. However, as the number of nodes was increased to 90, it was observed that there were 28 nodes after 5000 rounds. Conversely, the energy consumed after 5000 rounds was 0.000871 J for 50 nodes and 0.007184 J for 90 nodes. In this case more energy is consumed as the number of nodes increased. Remarkably, it is worthy of note to know that increasing node density (or nodes population) for a fixed network field and topology clearly affects the performance of the heterogeneous cluster based routing protocol in the WSN. Thus, while increasing number of nodes can somewhat enables more nodes to remain alive in WSN and thereby prolong network lifetime, the complexity and cost it will bring into the system must be taken into consideration for optimal performance.

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