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Energy Aware Buffer Management Routing Protocol (EABMRP) for Improving The WSN Lifetime Based on Energy Harvesting Model

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Abstract: Increasing demand for wireless communication has gained a huge attraction in several real-time application systems. In this field of wireless communication, wireless sensor networks are considered the most promising solution for monitoring the different type of conditional requirements. These networks can be deployed easily in hostile and hazardous environments. However, these networks are powered with a limited battery capacity hence, network lifetime is considered a challenging task in this field. In order to overcome this issue of network lifetime, we develop an energy harvesting and energy management protocol which is known as Energy Aware Buffer Management Routing protocol (EABMRP), to improve the network lifetime. According to the proposed approach, we consider the concept of energy harvesting and a buffer management scheme is developed to minimize the energy wastage during data collection, aggregation and transmission phase. The performance of the proposed approach is validated through an extensive experimental study which is conducted using MATLAB simulation tool. The obtained performance is compared with the existing techniques. The outcome of comparative analysis shows that the proposed approach can significantly improve the network lifetime.

Index Terms: WSN, energy aware, routing, energy harvesting, and buffer management.

I. INTRODUCTION

Nowadays, monitoring based application has gained huge attraction from research communication. This monitoring can be of any type such as visual monitoring or data sensing based monitoring. Several types of Visual monitoring based systems have developed but these systems are not suitable for hazardous environments hence, to overcome these issues researchers wireless sensor networks based monitoring systems have been developed. These types of WSN are widely adopted in various real-time motoring system such as healthcare, environmental monitoring, and temperature monitoring etc. Generally, these networks consist of sensing divides which are called as sensor nodes, processing units which are used for performing some desired computations, a power unit which is used for power supply to the sensor nodes and storage unit where sensed data is stored and aggregated to transmit to the destination node. These devices have limited battery capacity, and processing units which become a challenging task to maintain the network lifetime. Moreover, these sensor networks are deployed randomly in unattended environments where replacing these units is a tedious task [1]. Hence, network energy management is a crucial task in the field of WSN monitoring.

Nowadays, several approaches are introduced to mitigate the network lifetime issue. These approaches are based on the energy-aware routing protocols, load balancing in WSN, sleep-awake process, energy harvesting and scheduling etc… In this field, energy harvesting is considered as a promising technique which helps to generate energy from the natural power sources such as solar systems and thermal power etc. However, these systems provide unlimited energy power supply to the sensor nodes which is a useful task to improve the network lifetime. These energy harvesting sources are designed based on the hardware models where hardware impairments, and hardware lifetime etc. creates severe issues to hence, energy harvesting management is an important task [2]. In this work, we mainly focus on the development of harvested energy management scheme to improve the network lifetime and we assume that the sensor nodes are equipped with the solar power supply.

The harvested energy doesn't rely on time i.e. harvested energy always cannot be same hence the predicting energy harvesting is a crucial task. The low level of energy in the sensor nodes can cause serious impacts such as packet drop, data reliability and network lifetime. In order to overcome the issue of energy harvesting, several approaches are developed recently. Node activity management such as sampling rate of the sensor node and energy harvesting management can effectively improve the network performance in term of network lifetime [1]. In this field, energy harvesting routing approaches are adopted widely such as [2] where an intelligent EH approach is presented using MPPT tracking using solar power systems, Zhang et al. [3] presented Harvesting aware speed selection (HASS) for network energy management where an iterative process is implemented along with dynamic voltage scaling approach to maintain the network energy consumption and harvested energy saving. Similarly, geographical routing based approaches are also adopted widely where the 1-hop neighborhood node is selected for data transmission from source to destination node. Liu et al. [23] presented Easy-Go approach of geographical routing for packet forwarding for energy management, duty-cycle based approaches are also introduced to improve the network lifetime [24].

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The aforementioned techniques are based on the different type of forwarding scheme and some schemes are based on the packet forwarding, sleep-awake scheduling etc. which can be addressed using cross-layer based communication [4]. However, these schemes provide better lifetime performance but maintain the energy consumption and harvesting energy is an important task hence development of harvested energy management is a crucial task. In this work, our main aim is to study about different types of energy management and energy harvesting schemes and developing a novel approach to improve the network lifetime. Based on this objective we present a novel approach using a buffer management scheme which helps to reduce the network energy wastages. This approach also reduces energy wastages during data collection and aggregation. Rest of the article is organized as follow; section II provides a brief discussion about literature review, section III develops a proposed approach, section IV provides experimental results and discussion using proposed approach along with the comparative study to show the robust performance finally, section V provides concluding remarks.

II. LITERATURE SURVEY

This section mainly focuses on recent techniques for energy harvesting for Sensor Networks. In general, the energy harvesting process is mainly categorized into two main categories as energy harvesting from natural resources such as wind, thermal and vibration and energy-rich sources using wireless energy transfer mechanism. As discussed before, wireless sensor networks are adopted for various applications. A recent study [20] shows that the use of energy harvesting techniques with the conventional sensor network model can efficiently improve the network lifetime because energy harvesting techniques provide a continuous supply to the sensor node which can keep the nodes alive. Based on this assumption, Wu et. al. [21] developed a novel approach using packet forwarding mechanism for energy harvesting sensor networks. According to this approach, gradient aware clusters are formed based on the relative position of the node. This approach is based on the clustering model. In this process, the cluster head is selected based on a competition value which is obtained using storage effectiveness and relative distance. Based on clustering approach, Peng et al. [22] also developed a clustering model where a distributed energy neutral clustering approach is developed where the entire network is grouped into multiple clusters and a cluster head selection process is employed and this cluster head model used to share heavy traffic load among different cluster head. In this process, the cluster reformation frequencies can be reduced and overhead also can be reduced. Li et al. [2] also developed the energy-harvesting technique for WSN using solar energy-harvesting systems. This approach uses maximum power point tracking (MPPT) circuit-based approach for improving the power tracking performance for better harvesting of solar energy. This study shows that the network lifetime depends on the lithium battery hence, a charging control method is developed to reduce the cycle of charging and discharging. Several techniques have been introduced which shows that the energy harvesting techniques can significantly improve the performance of WSN in terms of a lifetime by enabling the energy generation from the ambient sources such as thermal, wind and Radio Frequency (RF) [5] etc. Recently, Dehwah et al. [6] introduced a solar-based energy harvesting approach to optimize the solar-powered sensor nodes. The main aim of this approach is to find the best network policy for maximizing the minimal energy among sensor nodes in the considered network. In order to obtain the optimal policy, forward dynamic programming is applied and later a greedy approach is also incorporated which helps to distribute the data and minimizing the complexity.

Nguyen et al. [15] discussed the advantages of the WSN and the contribution of energy-harvesting schemes to improve the communication performance of the network. The authors focused on the advantages of energy harvesting schemes for IoT (Internet of Tings) based applications. The main advantage of the energy harvesting technique is that the energy source replacement issues can be resolved by providing the continuous power supply with the help of ambient sources of energy. Various types of approaches have been introduced recently to overcome the issue of energy harvesting such as the development of an efficient model for power generation and energy-aware routing protocols etc. The hardware implementation can cause a higher cost of implementation hence routing protocols are considered as a promising solution to address these issues. In this work, authors focused on the energy harvesting and developed energy-harvesting-aware- routing for heterogeneous IoT based WSN applications. Similarly, Tang et al. [16] also focused on the IoT based application scenario for energy-harvesting in WSN. In this work, a Trust-Based Secure Routing approach is developed which helps to improve the security and maximizes the available energy for energy-harvesting for sensor networks. According to this process, source and sink communicate using disjoint paths and hence the data can be verified separately to ensure the security. Furthermore, a traceback approach is also implemented which uses a probability-based approach to identify the malicious node. This probability-based approach helps to cop-up the issue of security and battery levels.

The monitoring performance using wireless sensor networks depends on the various parameters. In these parameters, energy consumption, network utility parameters are considered an important parameter which can affect the network performance. In order to deal with these issues, Mahapatra et al. [17] developed a combined scheme using energy harvesting, wake-up radio and error control coding (ECC) schemes. To achieve the desired improvement in the network performance, a utility-lifetime maximization problem is formulated which is later resolved using gradient technique which uses Lagrange multiplier scheme. In this field of sensor nodes, the energy-harvesting schemes can improve the network capacity by generating sustaining energy for the sensor nodes. In general, the energy harvesting sensor nodes suffer from the issue of the uncertain energy harvesting process. Based on these assumptions, Cong et al. [18] developed an energy-harvesting approach for the WSN network lifetime improvement. In this work, authors have developed two approaches for computing the path probability of the network and statistical analysis approach. Further, these parameters points are used for computing the network connectivity based on the minimum and maximum probability. This connectivity is measured between, nodes based on the maximum and minimum values of probability.

Wang et al. [19]

developed a combined solution for the WSN lifetime performance enhancement by using cluster head selection technique and solar panel for saving solar energy. The network model is divided into three main categories

where first of all, the solar-powered cluster head placement strategy is explained using a distribution approximation approach. Later, this approach is extended as continuous space and developed an iterative approach based on the Weiszfeld technique. In the second stage of this approach, energy balancing approach and cluster head-re-selection technique are described. In the third stage of this work, a tour planning problem is formulated using wireless charging and data gathering in a tour. In order to solve this problem, polynomial time scheduling approach is presented.

Yukun et al. [10] discussed the issues related to the existing clustering schemes in the self-energized WSN. In order to address these issues, authors developed clustering routing algorithm based on solar energy harvesting (CRBS) approach in which a threshold-based technique is introduced which is used for reviving sensor node when there is a shortage of energy. On the other hand, the current energy harvesting level is used for validating the existence of a sensor node as the cluster head for the next round.

Yao et al. [11] developed an energy-aware clustering approach for self-organized WSNs called EBCS (Energy Balanced Clustering with Self-Energization) which uses the energy-harvesting technique to improve the cluster head selection. Moreover, it performs inter-cluster communication to recharge and utilize harvesting energy.

III. PROPOSED MODEL

In this section, we present a complete description of the proposed approach for an energy-harvesting approach for WSN. The complete section is divided into following sections: (a) problem definition & motivation (b) network considerations (c) energy & channel modeling and finally (d) routing protocol where cluster formation and head selection techniques are discussed.

3.1 Problem Definition & motivation

As discussed in the previous section that energy-harvesting sensor networks utilize ambient resources for harvesting the energy for the sensor node to perform the desired monitoring task. Energy efficiency and network lifetime related issues are considered a challenging task for the research community which can improve the network lifetime performance. Several schemes are present in current state which are based on the energy efficient routing protocol for prolonging the network lifetime. The energy-aware based schemes are generally categorized into two main categories as flat routing [7] and hierarchical routing [8] protocol. According to the flat routing schemes, each sensor node plays the same role in the entire network whereas in the hierarchical protocol, multiple clusters are formed and cluster heads (CH) are selected to forward the data packets to the sink node. Recent studies show that the hierarchical routing-based schemes provide better performance when compared with the flat routing protocols. Moreover, the performance of these schemes can be improved further by incorporating other information such as geographical location information, and energy level information during the data transmission phase. This nature of these protocols can be useful for energy-harvesting sensor networks because the energy level and status information can be used for optimizing the routing path using a central controller unit. These schemes have a significant impact on network lifetime but due to frequent information exchange about routing path and energy level, between sensor nodes can cause signaling overhead [9] and fails to provide the information about energy requirement and energy harvesting. Moreover, the available energy is based on the ambient energy sources which are vulnerable to the various environmental factors such as thermal power, light intensity/ conditions for solar power and other hardware impairments which is responsible for irregular energy which cannot accomplish the demand of real-time demand. Generally, the CH transmits packets to the remote sink node which require more energy, whereas cluster members transmit the data packet to the CH which consumes less energy, hence energy shortage occurs at the CH nodes. this issue can be addressed by developing a novel scheme to store the energy during the data transmission phase which can reduce the energy wastage. In this work, we discuss the energy storing routing protocol for energy-harvesting networks to enhance the network lifetime and communication performance.

3.2 Network Modeling

We consider a sensor network as energy-harvesting sensor network where a base station node and $\mathcal{N}$ number of sensor nodes are placed in a geographical area. These sensor nodes are deployed randomly in a given circular region where network radius is $\mathcal{R}$. The base station is placed in the center of the considered network area as depicted in figure 1.

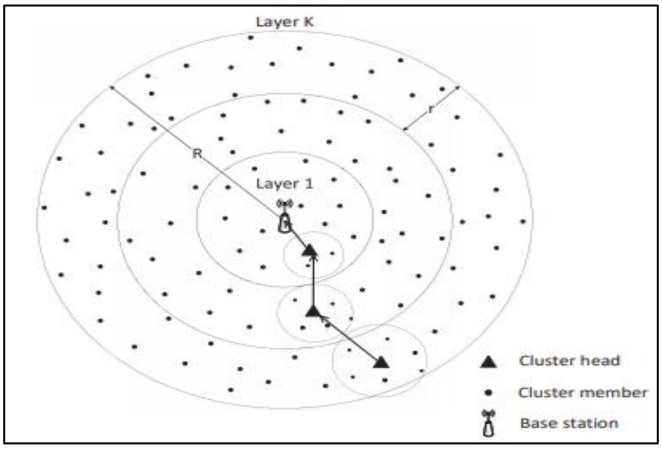

Figure1: WSN Deployment Model

The complete sensing region is divided into L sensing layers with the r width size where multiple sensor nodes are deployed. These sensor nodes performs data collect the collected data is transmitted towards the sink node based on the assigned routing protocol. Here, we have assumed that each sensor node has an energy harvesting device such as soar or thermal. It is assumed that each sensor node is equipped with an energy-harvesting device (i.e. wind or solar energy) and enough storage capacity which can store some amount of energy during transmission.

Let us consider that an arbitrary node is placed at (x_n, y_n) and the sink node is placed at (x_s, y_s), hence the distance between these two nodes is expressed as $d_n = \sqrt{(x_n - x_s)^2 + (y_n - y_s)^2}$.

Similarly, for two nodes $(x_{n_1} y_{n_1})$ and $(x_{n_2} y_{n_2})$,, the pairwise distance can be computed as: $d_{n_1 n_2} = \sqrt{\left(x_{n_1} - x_{n_2}\right)^2 + \left(y_{n_1} - y_{n_2}\right)^2}$.

The proposed routing scheme follows a hierarchical routing scheme where all sensor nodes are divided into two classes as a cluster head (CH) and cluster members (CM). Cluster members are responsible for sensing the data from the monitoring environment and this data is collected by CHs and data is aggregated to form a packet. Later, CHs forward these data packets towards the sink node. The complete process of this type of routing works in the rounds where each round contains two phase which is setup phase where cluster head selection is done and the steady phase where sensor nodes collect the information and transmit it to the CH node. This process poses several advantages such as avoiding the energy drainage due to large packet transmission, aggregation of collected information can be useful for the reducing the frequent data exchange and periodic cluster head selection can help to balance the energy consumption of the entire network.

In this work, we consider TDMA (Time Division Multiple Access) based approach for transmitting the data into multiple slots. Let us consider that total $\mathcal{N}$ number of slots are present which assigned to each node uniquely. The length of the time slot is denoted as t_s in which a packet of size P_L bits is transmitted and total $\mathcal{N}_F$ number of frames are available. Once the all packets are received at the CH from cluster members, the packets are transmitted to the sink node if enough energy is available which is required for transmission.

3.3 Energy and Channel Model

In this subsection, we discuss the energy modeling which presents a description of energy harvesting and energy consumption modeling. For the energy-harvesting WSN scenario, we have considered both free-space and multi-path fading channel modeling. In this work, the distance parameter is considered for channel selection i.e. if the computed distance (d) is less than d_0 then the ree-space model is selected otherwise multipath model is selected. Here we assume that the complete energy parameters are used for RF based communication model. In order to transmit a single bit data, the energy consumed by the RF unit can be expressed as:

$$e_{RF}(d) = \begin{cases} \epsilon_{mp} d^4, & d_0 < d \\ \epsilon_{fs} d^2, & 1 < d \leq d_0 \\ \epsilon_{fs}, & d \leq 1 \end{cases} \quad (1)$$

Where ϵ_{mp} and ϵ_{fs} denotes the energy (J) constants for multi-path and free-space channel model. On the other hand, the sensor node performs several other tasks during communication such as modulation, channel coding and spreading etc. which consumes e_{elec} amount of energy. Hence, the energy consumed by a cluster-member to transmit a packet can be expressed as:

$$\mathbb{E}_n^{\overline{CH}} = P_L(e_{RF}(d_{mn}) + e_{elec}) \quad (2)$$

Let us consider that $E_n^r(i)$ represents the residual energy and E_n^h denotes the harvesting energy respectively of node n for the current i^{th} frame. At this stage, a cluster member node n can transmit the data if it has sufficient energy for the transmission. This relation is given as:

$$\mathbb{E}_n^r \geq \mathbb{E}_n^{\overline{CH}} \quad (3)$$

i.e. if the cluster member node's residual energy is equal or more, then it can transmit the packet to other CHs. If enough energy is not available, then the sensor node waits until enough energy is accumulated. The residual energy of the current sensor node n can be computed as:

$$\mathbb{E}_n^r(i+1) = \mathbb{E}_n^r(i) + \mathbb{E}_n^h(i) - \mathbb{E}_n^{\overline{CH}} I_A \quad (4)$$

Where $A = \mathbb{E}_n^r(i) \geq \mathbb{E}_n^{\overline{CH}}$ is an indicator function which is set to 1 if $\mathbb{E}_n^r(i) \geq \mathbb{E}_n^{\overline{CH}}$ otherwise $A = 0$.

In general, if any node doesn't have enough energy for packet transmission then it doesn't participate in communication and the energy consumption for that particular node remains zero. On other hand, if the node is having sufficient energy then the energy consumption for that CH node can be computed as:

$$\mathbb{E}_m^{CH}(i) = I_{Tx_m}(i) \times \left(P_L \sum_{k=1}^{k_m - 1} I_{Tx_k}(i)\,(e_{da} + e_{elec}) + P_L e_{da} I_{k_m > 1} + e_n \right) \quad (5)$$

Where the first term of the given equation denotes the energy requirement for the transmitting the packet to the sink node, the second term of Eq. (5) denotes the energy consumed for receiving the data from its cluster member, and the third term of Eq. (5) denotes the energy consumed for data aggregation. k_m denotes the available number of nodes in the cluster, e_{da} denotes the data aggregation energy consumption and $e_n = P_L(e_{RF}(d_n) + e_{elec})$ is the minimum required energy for node n to transmit the packet directly to the sink.

Once the energy conditions are satisfied then the sensor node transmits the packet and all packets are received at the CH node where data aggregation process is implemented and the energy level of the CH node is measured for transmitting the packet to the sink node i.e. $\mathbb{E}_m^r(i) \geq E_m^{CH}(i)$ that means residual energy is more than the required energy for packet transmission. Hence, the CH node m can transmit the packet to the next hop or sink node, at the end, the remaining energy can be expressed as:

$$\mathbb{E}_m^r(i+1) = \mathbb{E}_m^r(i) + \mathbb{E}_m^h(i) - \mathbb{E}_n^{CH}(i) I_{\mathbb{E}_m^r}(i) \geq E_n^{CH}(i) \quad (6)$$

Based on this modeling, we consider some assumptions which are as follows:

(a) Each node is equipped with a battery which has enough storage capacity for data processing and transmission.
(b) Since the energy harvesting a continuous process hence energy can arrive at any time but we make use of harvested energy for transmitting the next packet to the destination node.
(c) The entire data packet which has arrived at the CH node where a single data packet is generated by aggregating the obtained information into one packet and later transmitted to the sink node.

3.4 Clustering and cluster head selection

In this sub-section, we present the proposed solution for cluster formation and cluster head selection. Let us consider that n_k number of nodes and m_k number of cluster head nodes are present in the k^{th} layer of the deployed network. All nodes are distributed randomly in the circular area with the density of ρ. Cluster member node n transmits the data packet to the corresponding CH node. The energy consumption to transmit the data packet using single slot in k^{th} layer can be given as:

$$\mathbb{E}_k^{member}(i+1) = l\mathbb{E}_{elec}(i) + l\varepsilon f_s \mathbb{E}[d_{mk}^2] \quad (7)$$

Where $[d_{mk}^2]$ denotes the squared distance in the k^{th} layer which is measured between cluster member and k^{th} layer, the expected value of $\mathbb{E}[d_{mk}^2]$ can be computed as:

$$\mathbb{E}[d_{mk}^2] = \int_0^{2\pi}\int_0^{\sqrt{\frac{2k-1}{m_k}}r} r^3\rho dr d\theta = \frac{2k-1}{2m_k}r^2 \quad (8)$$

For the cluster head node, the energy consumption can be given as:

$$\mathbb{E}_k^{CH} = l\mathbb{E}_{elec}\left(\frac{n_k}{m_k}-1\right) + l\mathbb{E}_{DA}\frac{n_k}{m_k} + l\mathbb{E}_{elec} + l\varepsilon_{f_s}\mathbb{E}[d_{mk}^2] + l\frac{\sum_{i=k+1}^{K} m_i}{m_k}\left(\mathbb{E}_{elec} + \varepsilon_{f_s}\mathbb{E}[d_{mk}^2]\right) \quad (9)$$

The total energy consumption for the cluster formation in k^{th} layer is given as:

$$\mathbb{E}_k^{cluster} = E_k^{CH} + \left(\frac{n_k}{m_k}-1\right)E_k^{memebr} \quad (10)$$

Based on these assumptions, the overall energy consumption of at the k^{th} layer can be computed as:

$$\mathbb{E}_k^{total} = l\mathbb{E}_{elec} + lE_{DA}n_k + m_k l\varepsilon_{f_s}\mathbb{E}[d_{mk}^2] + \sum_{i=k+1}^{K} m_i l\left(\mathbb{E}_{elec} + \varepsilon_{f_s} + \varepsilon_{f_s}\mathbb{E}[d_{mk}^2]\right) \quad (11)$$

With the help of the overall consumption of energy in this network, the optimal number of clusters can be selected by using total energy consumption with respect to the CH node and by setting their derivatives as zero. This can be given as:

$$\frac{\partial \mathbb{E}_k^{total}}{\partial m_k} = 0 \quad (12)$$

Where: $m_k = \sqrt{\frac{(2k-1)n_k}{(k-1)^2+k^2}}$.

After achieving the cluster formation related information, we apply a cluster head selection method. The proposed approach works in the round; hence we consider the first round and the network is divided into the different cluster using FCM (Fuzzy-C-Means) clustering approach which uses node location information and provides an objective function such as:

$$O_k = \sum_{i=1}^{m_k}\sum_{j=1}^{n_k} v_{ij}^m d_{ij}^2 \quad (13)$$

Where O_k denotes the objective function, m_k denotes CH node number in k^{th} layer, n_k denotes the total number of nodes, v_{ij} is a degree factor which can be computed as:

$$v_{ij} = \frac{1}{\sum_{c=1}^{m_k}\left(\frac{d_{ij}}{d_{cj}}\right)^{\frac{2}{m-1}}}.$$

Once the clusters are formed, the node which is near to the base station in the first round is selected as a cluster head, similarly, the upcoming rounds select for next cluster head. Later, the energy level of each CH node is also measured and if satisfies the below-given condition (in (14), then the cluster member is selected as a cluster head.

$$E_{CH}(l) > \delta E_{CH}(l-1) \quad (14)$$

$E_{CH}(l)$ denote the residual energy of cluster head node, δ denotes a constant parameter as $0 < \delta < 1$ and l denotes the current round. In order to develop more energy efficient and energy-harvesting network, each sensor node is configured in such a way that it stores some partial amount of energy during the cluster-member time period. Moreover, when a single unit is harvested, the harvested energy is stored into an energy buffer. Hence, the reserved energy is can be obtained as $E_n^{Reserved}(i) = E_n^{Reserved} + e_0$ where e_0 denotes the current energy state, similarly, remaining energy can be updated as $E_n^{remaining}(i) = E_n^r + e_0$. Due to this process, the overall energy supply can be enhanced which can help to improve the network lifetime.

IV. RESULTS AND DISCUSSION

In this section, we present a complete experimental study using the proposed energy-harvesting routing approach for WSN. The obtained performance of the proposed approach is compared with the existing energy-harvesting routing protocols. The complete experimental study is carried out using MATLAB simulation tool running on Windows platform as a simulation environment. In order to evaluate the performance, we consider that 100 and 2000 nodes are deployed randomly in a circular area with the radius R. The complete simulation parameters are presented in table 1.

Simulation Parameter	Value
Number of Nodes	100 and 2000
Simulation time	3000 sec
Length of slot (t_s)	0.0016
N_F	100
e_{elec}	50 nJ/bit
e_{da}	5 nJ/bit/signal
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/ m^4

The performance of proposed approach is compared with the existing approaches such as CRBS (clustering routing algorithm based on solar energy Harvesting) algorithm [10], ECBS (energy balanced clustering with self-energization) algorithm [11], R-MRPT (Randomized Minimum Path Recovery Time) [12], AODV-EHA (Energy Harvesting Aware Ad-hoc On-Demand Distance Vector Routing Protocol) [13], EHARA (energy-harvesting-aware routing algorithm) [14]. The performance measurement is carried out in terms of average energy consumption, packet loss ratio, and packet delivery ratio.

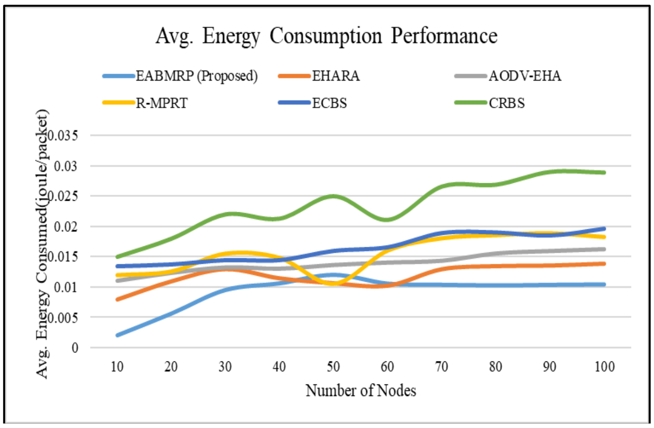

Figure 2: Average energy consumption

Figure 2 shows a comparative study in terms of average energy consumption. In order to evaluate the performance, we have deployed 100 number of sensor nodes and simulated for the given specific time duration. The obtained performance is compared with the existing techniques as depicted in figure 2. Obtained performance parameters are depicted in table 1 which shows that the proposed approach achieves better performance in terms of average energy consumption.

Table I: Average Energy Consumption Comparison

No. of nodes	EABMRP Proposed	EHARA	AODV-EHA	R-MPRT	ECBS	CRBS
10	0.002	0.0080	0.0110	0.0120	0.013	0.015
20	0.0056	0.0110	0.0123	0.0126	0.013	0.018
30	0.0095	0.0130	0.0132	0.0155	0.014	0.022
40	0.0106	0.0115	0.013	0.0148	0.014	0.0213
50	0.0120	0.0106	0.0136	0.0105	0.016	0.025
60	0.0105	0.0102	0.014	0.0160	0.016	0.0211
70	0.0103	0.0130	0.0143	0.0180	0.018	0.0266
80	0.01025	0.0135	0.0155	0.0185	0.019	0.0269
90	0.01035	0.0136	0.0159	0.0188	0.018	0.029
100	0.01042	0.0139	0.0162	0.0182	0.019	0.0289

Similarly, we measure the performance of the proposed approach in term of packet loss rate. To obtain the performance we have considered 100 nodes and simulated the scenario for a given duration. The comparative performance is depicted in figure 3 which shows that the proposed approach achieves better performance. According to this experiment, as the number of nodes is increasing the pocket drop rate increases due to the collision, energy-related issues, and clustering. The average packet drop rate is obtained as 0.40, 0.50, 0.53, 0.46 and 0.519 respectively using EABMRP (Proposed) EHARA, AODV-EHA, R-MPRT, ECBS, and CRBS techniques.

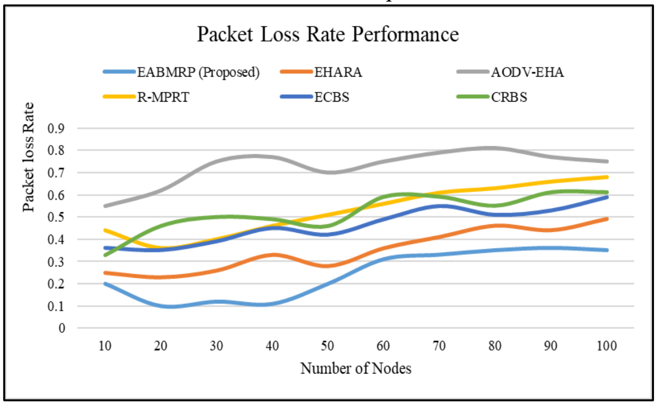

Figure 3: Packet Loss rate performance

In the next stage, we compute the packet delivery rate performance for a varied number of nodes. The packet delivery rate performance depends on the routing and clustering approaches. If the formed clusters are grouped in such a way that all nodes are having enough capacity for data transmission, then the packets can be delivered successfully. Generally, initial round nodes have more energy hence more packet delivery rate can be obtained. Figure 4 shows a comparative performance in terms of packet delivery.

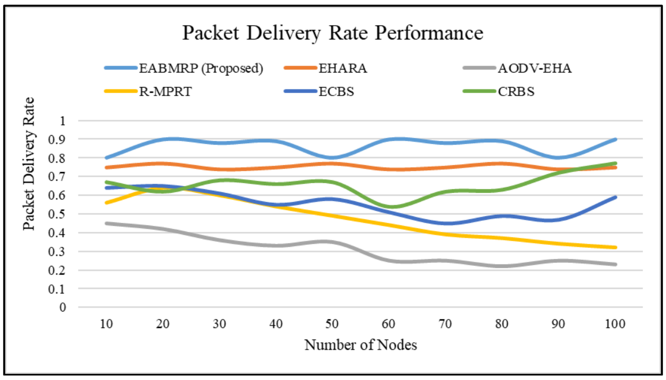

Figure 4: Packet delivery performance

The obtained performance is 0.86, 0.75, 0.31, 0.46, 0.55, and 0.65 using EABMRP (Proposed), EHARA, AODV-EHA, R-MPRT, ECBS and CRBS which shows that proposed approach achieves better when compared with the existing techniques. Finally, we present a comparative throughput performance which is obtained for a varied number of nodes. The throughput performance is obtained as 87%, 81.1%, 52.3%, 69.5%, 61%, and 71% using EABMRP (Proposed), EHARA, AODV-EHA, R-MPRT, ECBS and, CRBS. Similarly, we have computed the performance for 2000 nodes. The same simulation setup is used for this experiment as discussed for 100 nodes and performance is also measured using the same performance metrics such as energy consumption, packet delivery rate and throughput.

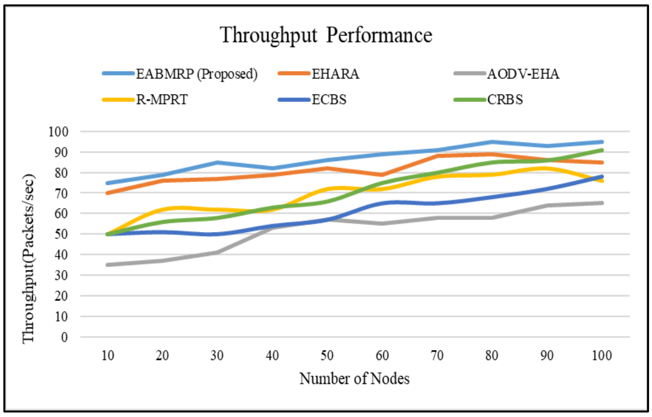

Figure 5: Throughput performance

Table II shows a comparative performance in terms of energy consumption for 2000 node scenario.

Table II: Energy Consumption performance for 2000 nodes

No. of Nodes	EABMRP (Proposed)	EHARA	AODV - EHA	R-MPRT	ECBS	CRBS
200	0.8	0.95	1.2	1.3	1.42	1.59
400	0.86	0.99	1.35	1.46	1.55	1.75
600	0.92	1.2	1.42	1.59	1.7	1.92
800	1.1	1.36	1.53	1.66	1.78	2.1
1000	1.16	1.36	1.55	1.69	1.83	2.19
1200	1.22	1.4	1.63	1.73	1.89	2.25
1400	1.29	1.5	1.7	1.82	1.95	2.3
1600	1.31	1.7	1.86	1.91	2.1	2.39
1800	1.36	1.85	2	2.09	2.3	2.6
2000	1.5	1.92	2.1	2.16	2.35	2.72

Based on this analysis, we present the comparative performance in a graphical form as depicted in figure 6 which shows that the proposed approach consumes less energy.

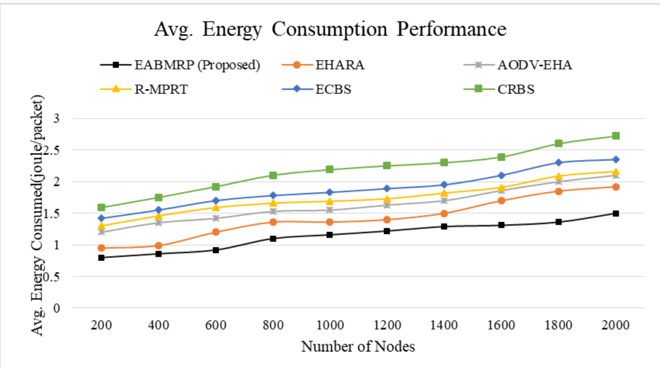

Figure 6: Average Energy Consumption performance for 2000 nodes.

However, an increased number of nodes will cause more energy consumption but existing approaches consume more energy which leads towards degraded network lifetime. Packet deliver performance is also evaluated for 2000 node scenario. The obtained performance is presented in Table III.

Table III: Packet Delivery Rate Performance for 2000 nodes

Number of Nodes	EABMRP (Proposed)	EHARA	AODV-EHA	R-MPRT	ECBS	CRBS
200	0.85	0.72	0.65	0.6	0.55	0.42
400	0.87	0.75	0.7	0.62	0.58	0.45
600	0.9	0.78	0.75	0.65	0.59	0.49
800	0.92	0.8	0.76	0.69	0.62	0.52
1000	0.94	0.81	0.8	0.71	0.67	0.59
1200	0.96	0.83	0.81	0.73	0.7	0.61
1400	0.95	0.85	0.8	0.75	0.7	0.63
1600	0.95	0.86	0.83	0.78	0.71	0.65
1800	0.97	0.9	0.85	0.8	0.73	0.68
2000	0.97	0.91	0.86	0.81	0.75	0.7

Based on these values, we present a graphical comparative performance of packet delivery rate as depicted in figure 7.

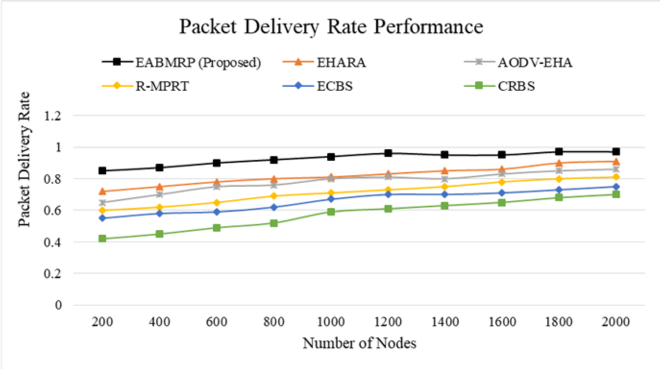

Figure 7: Packet Delivery performance

This study shows that the average packet delivery rates are obtained as 92.8%, 82.1%, 78.1%, 71.4%, 66% and 57.4% using EABMRP (Proposed), EHARA, AODV-EHA, R-MPRT, ECBS, and CRBS.

V. CONCLUSION

In this work, we have focused on energy-aware routing protocol in wireless sensor networks to improve the network lifetime. According to the WSN model, energy consumption during data aggregation, collection, and transmission leads to the degradation of network lifetime which is a serious issue. Thus, in this work, we focus on network lifetime based on the energy harvesting technique. To address this issue, a network routing protocol is developed using a buffer management scheme which helps to minimize energy consumption. Moreover, an efficient clustering-based model is also developed to improve the network lifetime.

REFERENCES

1. Srbinovski, B., Magno, M., Edwards-Murphy, F., Pakrashi, V., & Popovici, E. (2016). An energy aware adaptive sampling algorithm for energy harvesting WSN with energy hungry sensors. Sensors, 16(4), 448.
2. Li, Y., & Shi, R. (2015). An intelligent solar energy-harvesting system for wireless sensor networks. EURASIP Journal on Wireless Communications and Networking, 2015(1), 1–12

3. Zhang, B., Simon, R., & Aydin, H. (2013). Harvesting-Aware energy management for time-critical wireless sensor networks with joint voltage and modulation scaling. IEEE Transactions on Industrial Informatics, 9(1), 514–526.
4. Han, G., Dong, Y., Guo, H., Shu, L., & Wu, D. (2015). Cross-layer optimized routing in wireless sensor networks with duty cycle and energy harvesting. Wireless communications and mobile computing, 15(16), 1957-1981.
5. I. Ahmed, M.M. Butt, C. Psomas, A. Mohamed, I. Krikidis, M. Guizani, Survey on energy harvesting wireless communications: challenges and opportunities for radio resource allocation, Comput. Netw. 88 (2015) 234–248.
6. Dehwah, A. H., Shamma, J. S., & Claudel, C. G. (2017). A distributed routing scheme for energy management in solar powered sensor networks. Ad Hoc Networks, 67, 11-23.
7. Singh, S. P., & Sharma, S. C. (2015). A survey on cluster based routing protocols in wireless sensor networks. Procedia computer science, 45, 687-695.
8. Liu, X. (2015). Atypical hierarchical routing protocols for wireless sensor networks: A review. IEEE Sensors Journal, 15(10), 5372-5383.
9. Jumira, O., Wolhuter, R., & Zeadally, S. (2013). Energy-efficient beaconless geographic routing in energy harvested wireless sensor networks. Concurrency and Computation: Practice and Experience, 25(1), 58-84.
10. Yukun, Y., Zhilong, Y., & Guan, W. (2015). Clustering routing algorithm of self-energized wireless sensor networks based on solar energy harvesting. The Journal of China Universities of Posts and Telecommunications, 22(4), 66–73. doi:10.1016/s1005-8885(15)60669-0.
11. Yao Y K, Wang G, Ren Z, et al. Energy balanced clustering algorithm for self-energized wireless sensor networks. Chinese Journal of Sensors and Actuators, 2013, 26(10): 1420−1425
12. D. Hasenfratz, A. Meier, C. Moser, J. J. Chen, and L. Thiele, "Analysis, comparison, and optimization of routing protocols for energy harvesting wireless sensor networks," in Proc. of SUTC'10, Jun 2010, pp. 19–26 R-MRPT
13. P. Gong, Q. Xu, and T. M. Chen, "Energy harvesting aware routing protocol for wireless sensor networks," in Proc. of CSNDSP'14, Jul 2014, pp. 171–176
14. Nguyen, T. D., Khan, J. Y., & Ngo, D. T. (2018). A Distributed Energy-Harvesting-Aware Routing Algorithm for Heterogeneous IoT Networks. IEEE Transactions on Green Communications and Networking, 1–1.
15. Nguyen, T. D., Khan, J. Y., & Ngo, D. T. (2017, May). An effective energy-harvesting-aware routing algorithm for WSN-based IoT applications. In Communications (ICC), 2017 IEEE International Conference on (pp. 1-6). IEEE.
16. Tang, J., Liu, A., Zhang, J., Xiong, N. N., Zeng, Z., & Wang, T. (2018). A trust-based secure routing scheme using the traceback approach for energy-harvesting wireless sensor networks. Sensors, 18(3), 751.
17. Mahapatra, C., Sheng, Z., Kamalinejad, P., Leung, V. C., & Mirabbasi, S. (2017). Optimal power control in green wireless sensor networks with wireless energy harvesting, wake-up radio and transmission control. IEEE Access, 5, 501-518
18. Cong, H., Li, Q., Zhou, C., & Yang, Q. (2018, March). Analysis on Connectivity of Energy Harvesting Wireless Sensor Networks Based on Simulation. In 2018 International Conference on Computing, Networking and Communications (ICNC) (pp. 762-768). IEEE.
19. Wang, C., Li, J., Yang, Y., & Ye, F. (2018). Combining solar energy harvesting with wireless charging for hybrid wireless sensor networks. IEEE Transactions on Mobile Computing, (1), 1-1.
20. Vullers R J M, Schaijk R V, Visser H J, et al. Energy harvesting for autonomous wireless sensor networks. IEEE Solid-State Circuits Magazine, 2010, 2(2): 29-38.
21. Wu, D., He, J., Wang, H., Wang, C., & Wang, R. (2015). A hierarchical packet forwarding mechanism for energy harvesting wireless sensor networks. IEEE Communications Magazine, 53(8), 92-98.
22. Peng, S., Wang, T., & Low, C. P. (2015). Energy neutral clustering for energy harvesting wireless sensors networks. Ad Hoc Networks, 28, 1-16.
23. Liu, C., Fang, D., Hu, Y., Tang, S., Xu, D., Cui, W, & Chen, H. (2018). EasyGo: Low-cost and robust geographic opportunistic sensing routing in a strip topology wireless sensor network. Computer Networks, 143, 191-205.
24. Shaikh, F. K., & Zeadally, S. (2016). Energy harvesting in wireless sensor networks: A comprehensive review. Renewable and Sustainable Energy Reviews, 55, 1041-1054.

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