Energy aware reliable routing model for sensor network enabled internet of things environment

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ABSTRACT

Wireless sensor networks (WSNs), which are facilitated by the internet of things (IoTs), can be difficult to improve the lifespan of the network target area. Although the hotspot issue (i.e., the cluster head closest to the base station fails quickly) is mitigated by the clustered-based routing technique, it still has an important effect on the network's lifespan and target area. However, improper distribution of load between cluster heads has been shown to negatively impact network lifespan efficiency, so even though unequal clusters have been utilized successfully to tackle the hotspot issue, further work is needed. This study provides an energy-aware reliable routing (EARR) model for resolving the hotspot as well as load balancing issues simultaneously. To extend the lifespan of the network, the EARR model effectively minimizes energy consumption by the cluster heads using enhanced multi-objective optimization parameters. Further, EARR provides improved routing optimization metrics to improve data delivery with energy efficiency, less delay, and packet loss. The results of the experiments demonstrate that the EARR model provides excellent throughput and lifespan efficiency with low delay and communication overhead.

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1. INTRODUCTION

In the current environment of the internet of things (IoTs), wireless sensor networks (WSNs) play an important role in both everyday as well as industrial contexts [1], [2]. In IoT-enabled WSNs, sensor nodes collect data about the surrounding environment and relay that information to the IoT edge gateway server or base station (BS) based on predetermined events. Since the devices that collect data are so small and have relatively little energy and processing capabilities, the data has to initially travel utilizing a series of intermediary nodes before reaching the IoT edge gateway server [3], [4]. This causes several problems, including energy inefficiency, delays, and additional communication costs [5], [6].

These kinds of problems cannot be tolerated when it comes to the deployment of applications in environments like agricultural precision farming, the creation of smart cities, medical care, automation of homes, or industrial IoTs [7], [8]. Hence, the network is divided into separate groups/clusters so that communication can be carried out in an energy-efficient manner, consequently resolving the problems encountered by the application mentioned above [9], [10]. By collecting data from their peers, the cluster heads (CHs) aggregate it before sending it back to the edge server using other CHs, which greatly extends the lifespan of the network. However, the present cluster-based routing strategy does not solve problems like delay, throughput as well and the energy-hole issue (where CHs nearer to the edge server consume energy faster than those further away) [11], [12]. In addition, the current models impose additional computational burden when partitioning entire networks and also have weak reliability (i.e., the load-balancing method) when it involves delivering cutting-edge workflow applications that need quality of service (QoS) guarantees [13], [14]. As a result, after a particular number of rounds are complete, there are energy imbalance problems inside the network [15], [16].

An efficient CHs as well as routing optimization technique is currently being utilized to optimize delay and energy, whereas unequal clustering was additionally implemented to satisfy the resulting energy hole [17], [18]. Nevertheless, due to unequal clustering environments, relatively little effort has been made to tackle route optimization with QoS constraints. In addition, induced load-balancing difficulties that impact overall QoS are becoming a problem when it comes to the deployment of contemporary workflow applications [19]. The work has the objective of developing the energy aware reliable routing (EARR) architecture for IoT-WSNs because of the limitations and demands of modern IoT workflows in terms of QoS. The EARR employs a novel CH selection mechanism and routing optimization techniques. The significance of the research work are given as follows: i) the EARR model improves the lifetime of IoT-WSNs; ii) the EARR model is efficient in reducing routing delay with less communication overhead; and iii) the proposed model can attain better throughput in comparison with current routing approaches.

This paper is organized as in section 2, related work concerning the routing optimization to enhance network lifetime with QoS assurance to provision IoT applications. Section 3, the proposed methodology is discussed. Section 4, the simulation study considering different parameters is performed. Section 5, the research performance improvement is provided and future enhancements are discussed.

2. RELATED WORK

This section studies various recent routing approaches to improve network lifetime meeting IoT application reliability. Jagan and Jayarin [20], the researchers present a new fully-connected energy-efficient-clustering (FCEEC) method that utilizes the electro-static-discharge algorithm (ESDA) to construct a network that is completely connected having the shortest possible routing between sensor nodes (SNs) towards CH in a context that involves several hops. This will allow the entire network to be more economical in terms of energy. By achieving full communication among the sensor nodes in a highly energy-efficient manner, the presented ESDA extends the lifespan of the network. By drastically decreasing the number of nodes that have died, ESD extends the lifespan of the network. Finally, the experiment's findings demonstrated superior performance in comparison to other traditional CH selection approaches in terms of network latency, packet delivery, energy efficiency, and dead node count. Alharbi *et al.* [21], in this study, they concentrate on gathering information from dispersed IoT nodes that are linked together employing WSNs. They discuss routing and clustering, two related problems that affect IoT-based WSNs on a grand scale, and suggest a new technique to resolve both problems at once. The routing and clustering improvements come in the form of area-based clustering, which relies on the range of transmission of individual nodes within a network. CH is chosen to ensure reliable failover routing throughout the clustering method. When multiple possible routes exist, selecting the one with the fewest hops is the most efficient. The outcomes are evaluated next to industry standard protocol benchmarks. Both theoretical and simulated findings show that the system's topology is robust, its lifespan is extended, its node density is efficiently managed, and its total capacity is increased.

Han *et al.* [22], in this research, they present a hierarchical clustering-based adaptable (HCA) routing method for energy-harvesting-WSNs to ensure seamless transfer of data across the entire coverage area. To begin, a protocol for routing that relies on clustering hierarchy has been suggested as a means of bringing the energy use of nodes into a more even distribution. The total amount of nodes operating in the energy-harvesting phase is next suggested to be dynamically controlled, allowing for continuous target coverage. The computational and experimental findings validate the conclusion that the presented HCA method can accomplish continuous target coverage utilizing energy-harvesting technologies for a longer period than the traditional routing method along with a higher probability of success. Lenka *et al.* [23], the clustering method was employed in cluster-based routing protocol with the static hub (CRPSH) for WSNs to decrease the amount of redundant information. The multipath technique can also improve the suggested protocol's dependability. CRPSH's goal is to decrease the burden of managing packets so that the network can run for longer. The Castalia simulator is used to do all the different simulations. It is discovered that the suggested method extends the lifespan of IoT infrastructure networks while decreasing their energy requirements.

Kaur *et al.* [24], for IoT-enabled WSNs, this study details an environmentally friendly hybrid congestion management strategy. To address the problem of energy holes, it employs an unequal clustering method that reduces the power consumption of node sensors with limited battery life. Additionally, a new congestion reduction strategy that utilizes two-class priority is suggested, which drastically cuts down on communication latency. To prove the successful result of the suggested strategy, comprehensive simulations, and actual tests are carried out. Compared to state-of-the-art methods, the suggested system improves upon metrics including network life expectancy, effective packet delivery, and average throughput. To mitigate the hot-spot issue, the researchers of [17] suggested the unequal clustering (UC) algorithm utilizing the type-2 fuzzy rule Takagi-Sugeno-Kang (TSK) and the explicit state-transition calculus reduction (ESCR) involving intervals. The ESCR solves the hotspot issue and extends the lifespan of the network through reduced computing complexity (considering factors like the distance between each BS, the number of nodes, and the amount of energy each node has not utilized). The CH and cluster size are optimized based on the results of a fuzzy rule [25] optimization that considers multiple objectives. These objectives include device density, remaining energy, as well as proximity away from the sink. When choosing the CH or relay nodes, nevertheless, ESCR fails to consider QoS [18]. The relay nodes function as a hopping node, shortening the path from the remote sensing device to the BS/sinks [26], [27]. In finding more optimal path in [28] used ant colony optimization technique and in [29] introduced dynamic routing mechanism to enhance energy efficiency; however, the reliability of less packet failure is not considered in routing decision. In addressing the research issues of ensuring lifetime and providing reliability the following methodology is provided in the next section.

3. PROPOSED METHODOLOGY

This section presents the proposed methodology of energy aware reliable routing model for IoT-WSNs. The architecture of EARR is given in Figure 1. The work first discusses the standard CH algorithm; then, identifies the limitation of the current method, and later introduces an improved CH selection algorithm under unequal clustering environment to provide improved performance. Finally, a reliable routing optimization is introduced.

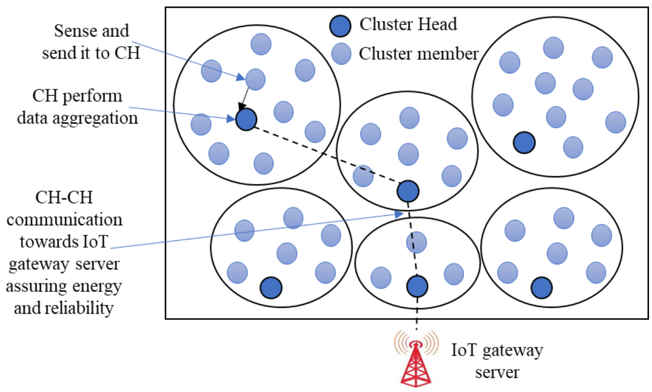

Figure 1. Block diagram of different phases of energy aware reliable routing model for WSNs

The energy consumption model $C_{\mathbb{E}}$ of the proposed cluster-based routing model is obtained through the (1):

$$C_{\mathbb{E}} = K_{\mathbb{E}} + L_{\mathbb{E}} + D_{\mathbb{E}} \quad (1)$$

where $K_{\mathbb{E}}$ defines energy consumed for changing state from sleep to active and vice versa, $L_{\mathbb{E}}$ defines energy consumption of the processing unit, and $D_{\mathbb{E}}$ defines energy consumption of the radio unit for performing transmission.

3.1. Standard cluster head selection

The baseline CH selection algorithm based on low energy adaptive cluster hierarchy (LEACH) [18] using threshold parameter $T(d)$ is obtained using the (2):

$$T(d) = \begin{cases} \frac{r}{1-r\times[\varphi mod(1/r)]}, & if\ d\epsilon S; \\ 0, & Otherwise. \end{cases} \quad (2)$$

where r outlines the mean ratio among cluster-heads concerning total IoT devices, φ expresses current round id which changes involving $0 \leq \varphi < \infty$, and S outlines IoT devices that have not been cluster-heads for session

$1/r$ rounds. In the traditional LEACH model, the CH is selected using (2). However, using (2) for CH selection induces overhead (i.e., hotspot problem) to the node closer to the base station.

3.2. Cluster head selection with varying probability

Usually, the IoT device will possess the same communication range with density δ. However, in addressing the hotspot problem in this work, a modified CH selection is introduced with each cluster having a different cluster size using the (3):

$$T(d) = \begin{cases} \frac{r(d)}{1-r(d)\times[\varphi mod(1/r(d))]}, & if\ d \in \bar{S}; \\ 0 & Otherwise. \end{cases} \quad (3)$$

where d defines the cluster-head for round $1/r(d)$, $\bar{S}$ outlines IoT devices that have not been cluster-head yet for the corresponding round. Therefore, different nodes will have varied different probability of being cluster-head. In (3) the parameter r is normalized concerning the overlapping area of some IoT node d and optimization of r is done using the (4):

$$r(d) = \propto \times\ \omega(d), \quad (4)$$

where $\propto$ defines the mean size of the cluster and ω represents IoT nodes normalized overlapping area.

3.3. Cluster head selection using multi-objective parameter

The K_y, function has been considered to select the CH that brings more energy balance in the network. the K_y with the best value is chosen as CHs. The cost function to select CH is given in the (5):

$$K_y = \frac{M_{\rightarrow} * D_m}{(X_v * D_x) * (\mathcal{E} * D_e)} \quad (5)$$

where $M_{\rightarrow}$ is used for denoting the mean distance between the neighboring IoT devices, $\mathcal{E}$ is used for denoting the starting energy levels, X_v is used for denoting the IoT device size, and D_m, D_x, D_e are used for defining the weights for every objective-parameter which usually ranges from 0 to 1. The objective parameters are the starting energy, mean distance, and the total count of the IoT devices. The weights are usually utilized for the selection of the objective parameter. The mean distance between the IoT device and the neighbors $M_{\rightarrow}$ is evaluated using the (6):

$$M_{\rightarrow} = {}^{K_h}/_{\mathcal{A}} \quad (6)$$

where $\mathcal{A}$ has been used to denote the distance of the neighbors from the IoT devices and K_h is the total distance of the IoT devices.

3.4. Reliable routing optimization

The non-CH IoT devices which are very far from the IoT gateway server, and the cluster consume higher energies for the data transmission to send the information to the given CH. In this situation, an intermediary IoT device is used for the data transmission to the IoT gateway server or the CH. The main aim of this routing work is to find the high-reliability path consuming the least energy. In every cluster, the IoT device that is far from the CH or the IoT gateway server utilizes the link/path selective variable $L_{\mathcal{M}}$ for finding the optimal path to the IoT gateway server or CH using the (7):

$$L_{\mathcal{M}} = \mathcal{E}_v + \mathcal{G}_l + \bar{\mathcal{G}}_l + \mathbb{L}_l \quad (7)$$

where $\mathcal{E}_v$ is used for denoting the residual energy for every energy category, v is used for denoting the IoT node having the precise category of energy, $\mathcal{G}_l$ is used for denoting the anticipated hops, $\bar{\mathcal{G}}_l$ is used for denoting the inverse of the anticipated hops and $\mathbb{L}_l$ is used for denoting the least loss of data parameter.

3.5. Algorithm and block diagram

The steps involved in designing an EARR model are given in Algorithm 1. The model first deploys the IoT device across the sensing environment (step 2). Then, unequal cluster formation is done similarly to address the hotspot problem i.e., the cluster head closer to the IoT gateway has a lesser number of densities in comparison with away from the IoT gateway server (step 3). Then, CH is selected using a multi-objective function defined in (5) to improve more balanced energy consumption. The time division medium access (TDMA) is used for intra-cluster communication to reduce collision in intra-cluster communication (step 5).

Then, in enhancing the inter-cluster routing performance i.e., keeping energy low, and packet loss low, with a lesser number of hops, (7) is used (step 6). Once the packets from all the CHs reach the IoT gateway server it is considered one round is done; then, the iteration count is increased by 1 (step 7); then, go to step 4 for the reclustering process. The node that was CHs in the previous round will not take part in the process of CH selection (step 8). The adoption of improved CH selection with routing optimization aids the EARR to achieve improved throughput and lifetime enhancement which is experimentally shown in Algorithm 1.

Algorithm 1: EARR model

Step 1. start
Step 2. Deploy network with δ IoT device across 100×100 meters, iteration = 0.
Step 3. Unequal cluster formation is done to address hotspot problems.
Step 4. Cluster head selection:
every IoT node sends its energy level and location information to the IoT gateway server.
using Equation (5), the IoT gateway server selects the node with the best K_y as CHs.
all the remaining node within the cluster head radius joins the respective cluster head.
Step 5. Packet sensing and routing (Intra-cluster communication):
member node senses the packet like temperature and humidity.
the packet is communicated to CHs through TDMA schedule.
Step 6. Routing Optimization (Inter-cluster communication):
The CHs collects the data from member device and aggregates it
The aggregated data is communicated to CHs with the best $L_{\mathcal{M}}$ towards IoT gateways.
Step 7. iteration = iteration + 1.
Step 8. Go to step 4.
Step 9. Stop

4. RESULT AND ANALYSIS

Here, the experiment is conducted to validate the outcome achieved using EAR, reliable and energy-efficient routing (REER) [19], LEACH [26], and low energy adaptive cluster head- quality of service (LEACH-QoS) [26], and the sensoria simulator [30] is used for evaluating different routing models. All the models considered for evaluation are implemented using C# programming language. The parameters used for studying the performance of the different models are set as follows network area is set to 100m×100m, one IoT gateway server is placed outside the sensing region, IoT device is varied between 200 to 800, motion sensors with sensing and transmission range is set to 5 meters and 10 meters, respectively, initial energy is fixed to 0.1 j with radio unit energy consumption is set to 50 nj/bit, amplification energy (Emp) is set to 100 pJ/bit/m2, idle energy consumption (Eelec) is set to 50 nj/bit, control packets size is set to 512 bits, data packets size is set to 5,000 bits, transmission speed is set to 512 bits/s, bandwidth is set to 10,000 bits/s with sensing time of 0.1s. The metrics considered for validating the routing model are lifetime, communication delay, control channel communication overhead, and throughput.

4.1. Lifetime performance

This section studies the lifetime performance of the proposed EARR with other existing approaches such as LEACH, LEACH-QoS, and REER. The lifetime performance is studied by varying the node size from 200 to 800 IoT devices as shown in Figure 2. The result attained in Figure 2 shows the EARR improves lifetime performance by 75.01%, 51.68%, and 13.62% over LEACH, LEACH-QoS, and REER, respectively. The significant lifetime improvement by the proposed EARR model is due to the adoption of unequal clustering with an improved CH selection method introduced in (3) and (5).

4.2. Communication delay

This section studies the communication performance of the proposed EARR with other existing approaches such as LEACH, LEACH-QoS, and REER. The communication delay performance is studied by varying the node size from 200 to 800 IoT devices as shown in Figure 3. The result attained in Figure 3 shows the EARR reduced communication delay by 57.07%, 50.69%, and 8.56% over LEACH, LEACH-QoS, and REER, respectively. The significant communication delay reduction by the proposed EARR model is due to the adoption of improved routing optimization introduced in (7).

4.3. Control channel overhead

This section studies the control channel overhead performance of the proposed EARR with other existing approaches such as LEACH, LEACH-QoS, and REER. The control channel overhead performance is studied by varying the node size from 200 to 800 IoT devices as shown in Figure 4. The result attained in Figure 4 shows the EARR reduces control channel overhead by 23.54%, 23.99%, and 12.26% over LEACH, LEACH-QoS, and REER, respectively. The significant control channel overhead reduction by the proposed EARR model is due to the adoption of unequal clustering with improved routing optimization introduced in (7).

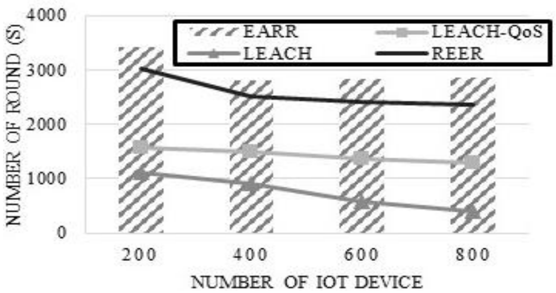

Figure 2. Lifetime performance

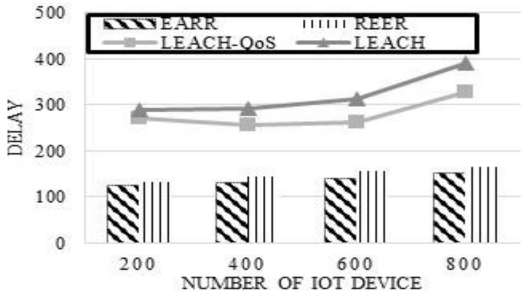

Figure 3. Communication delay

4.4. Throughput

This section studies the throughput performance of the proposed EARR with other existing approaches such as LEACH, LEACH-QoS, and REER. The throughput performance is studied by varying the node size from 200 to 800 IoT devices as shown in Figure 5. The result attained in Figure 5 shows the EARR improves throughput performance by 49.15%, 58.51%, and 12.8% over LEACH, LEACH-QoS, and REER, respectively. The significant throughput improvement by the proposed EARR model is due to the adoption of unequal clustering with the improved CH selection method introduced in (5) and routing optimization in (7).

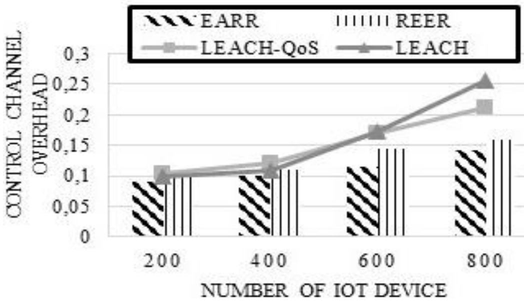

Figure 4. Communication overhead

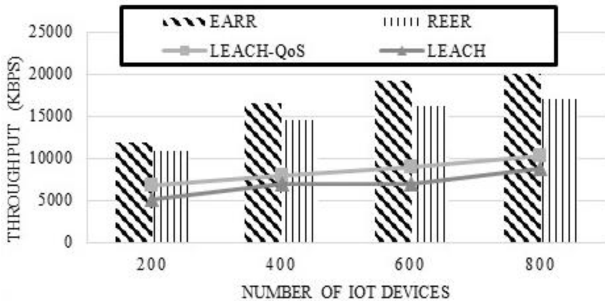

Figure 5. Throughput

5. CONCLUSION

Among the most desirable goals of WSN is to reduce the amount of energy that sensor nodes need to use and to find a solution to the issue of hotspots. Recently, several strategies have been successfully implemented to reduce energy consumption. Currently, IoT and big data applications that utilize the sensor nodes will demand increased availability of data in real-time. The currently available approaches are not suitable for applications like this, and only a very small number of research investigations have emphasized uneven clustering networks. Hence, this work presents the EARR model, which reduces packet loss, delay, and energy consumption. The experimentation has been performed and has been compared with the existing LEACH, LEACH-QoS, and REER models. The proposed EARR model decreases the overhead of the control channel, and delay in communication and increases the lifetime and throughput of the wireless sensor network when compared with the LEACH, LEACH-QoS, and REER models. Based on the outcome, we conclude that the EARR model is adaptable to networks of varying densities by creating an uneven clustering environment. Using metrics like delivery ratio and rate of node decay, the proposed approach will be validated in future study.

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