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An Energy Efficient Approach for Improving Network Performance of Wireless Sensor Network Assisted Internet of Things Applications

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Abstract

Internet of Things (IoT) is an important technique of today's wireless communications. It is based on the collection of various sensor nodes through Wireless Sensor Network (WSN). Sensor nodes provide sensing services to IoT systems with limited power and storage. Since battery replacement or recharging in sensor nodes is practically impossible, the power consumption is considered to be one of the key designs in WSN-assisted IoT applications. The clustering technique is one of the most efficient methods for power conservation in the energy-constrained network. The appropriate choice of a cluster head enhances the balance of the load in the network, reducing energy consumption and extending the network lifetime. A resilient routing algorithm for cluster head selection based on residual energy is proposed in this paper. In each round, the proposed algorithm analyzes residual energy, current round energy, and the optimum value of cluster heads to select the next group of cluster heads for the network. The proposed algorithm is intended for smart IoT applications such as environmental monitoring, smart cities, and systems. In comparison to current methods, simulation experiments show that the proposed algorithm significantly improves network reliability, network lifetime, and network throughput.

Keywords: Internet of Things, Wireless Sensor Networks, Resilient routing algorithm, CH selection, Network performances.

Introduction

Recently the Internet of Things (IoT) has become the most interesting technologies due to the diverse applications such as health care monitoring, smart phones, military, disaster management, and other surveillance systems. Figure 1 depicts the Internet of Things' generic architecture. The IoT incorporates sensing, connectivity, networking, and cloud computing into these control sectors. Wireless Sensor Networks (WSNs) are widely used in a wide range of Internet of Things (IoT) applications. Recent advancements make it easier for people to go about their regular lives. Smart devices in IoT-assisted WSN applications are connected to the Internet through a device known as a Base Station (BS) or gateway router. There are several types of users who are interested in obtaining the data of relevant IoT devices like, doctors, industrialists, and smart home users. Therefore, the IoT provides immediate access to information related to any device, resulting in increased productivity and efficiency [1].

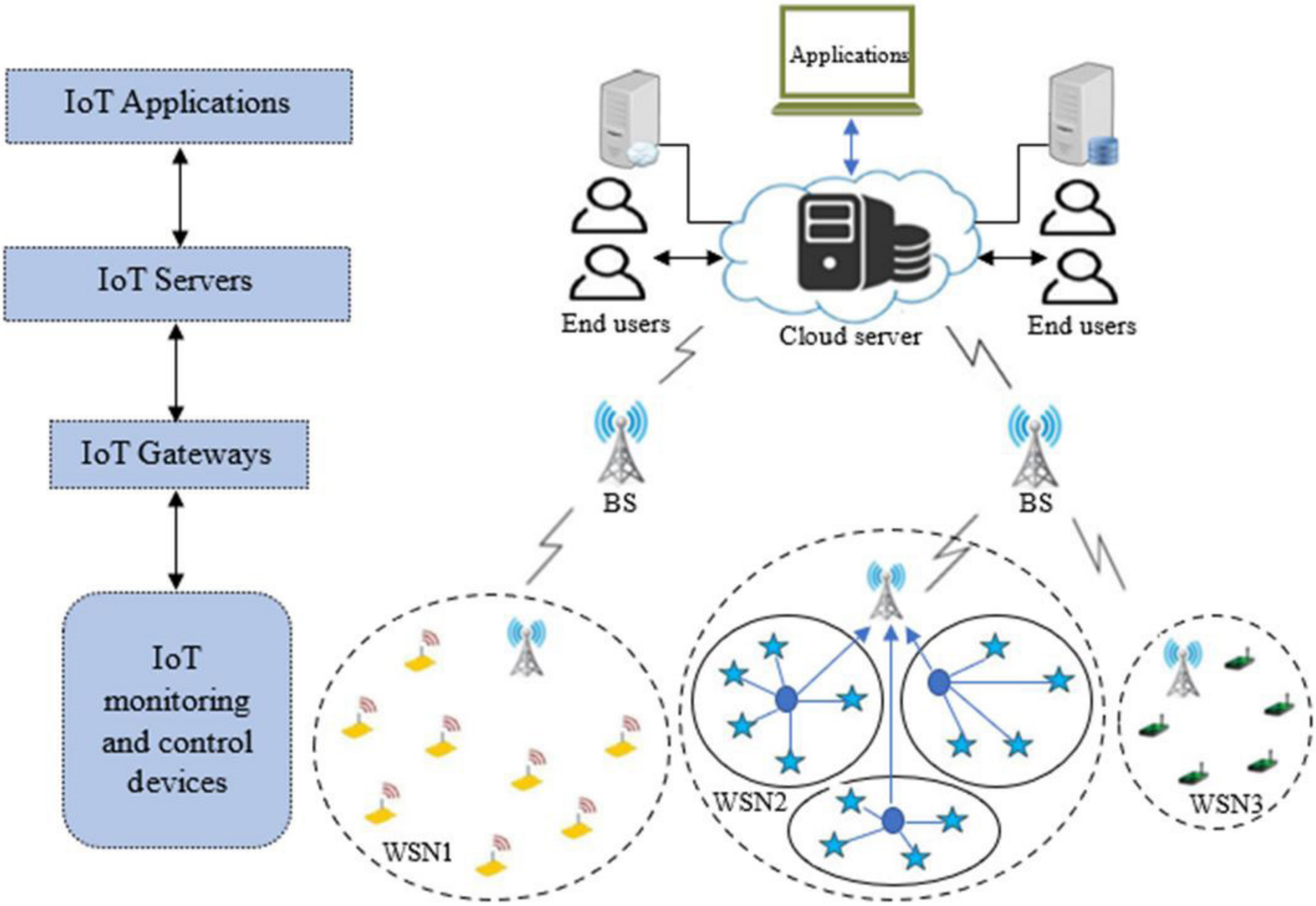


Figure 1: Generic Internet of Things architecture

The WSN is a network that connects the virtual and physical worlds. Wireless sensor nodes are in charge of sensing and transmitting data to the Internet. Wireless sensor nodes are used to monitor a variety of physical and environmental parameters in a network field. Given the impossibility of recharging the sensor battery, the data routing method from the sensing node to the BS should be designed in an energy efficient manner [2].

Unlike an ad-hoc network, a WSN designed for IoT applications faces a variety of issues, including the number of sensor nodes, hardware, communication mode, battery and computational cost. In addition to sensing, sensors used in the IoT paradigm are given extra functionality, and they must deal with new concerns such as Quality of Service (QoS), security, and power management [3]. Some of these difficulties are solved by implementing various technological enhancements in the WSN's primitive protocols and schemes. Resilient routing mechanism, data redundancy, dynamic network size, less reliable medium, heterogeneous network, and multiple BS all provide substantial problems to QoS requirements in IoT-based WSNs. The fundamental goal of WSN routing is to identify the most energy-efficient path and transmit data from sensor nodes to the BS in order to extend the network's lifetime.

Clustering is one of the most effective approaches for managing network energy consumption and extending network lifetime. The clustering technique creates a hierarchical structure of clusters or groups of sensing nodes that collect and transmit data to the cluster head (CH). Sensed data are combined by the CH and sent to the BS. LEACH is a traditional clustering algorithm that takes energy into account when routing data hierarchically. The network is organized into clusters, and each sensor node delivers data to the appropriate CH. For each round, the LEACH protocol selects CHs at randomly in a stochastic manner. The CH connects to each cluster member node to collect the sensed data. Time Division Multiple Access (TDMA) schedules are assigned by the CH to each cluster member. The Member Cluster can transfer data during the selected time period. The data must be verified and compressed before interacting with the BS.

Choosing a CH is tough since numerous parameters must be considered while selecting the optimal node in the cluster [4]. The distance between nodes, residual energy, mobility, and throughput of each node are important factors in the routing mechanism. The LEACH algorithm improves the network's lifetime for direct and multi-hop transmission, although it still has a number of drawbacks CHs are randomly picked, thus proper distribution and an optimum solution cannot be guaranteed. During CH selection, nodes with lower energy levels have the same priority as those with higher energy levels. As a result, when a low-energy node is chosen to serve as CH, it dies out rapidly, resulting in a shorter network lifetime [5].

The goal of this paper is to choose the CH based on crucial criteria such the initial energy, each node's residual energy, the energy of each round, and the ideal number of CHs in the network. The improvement is achieved to the traditional LEACH algorithm. The residual energy of the chosen CH is examined during each round after selecting the upper energy node as a CH. The selected CH will continue a CH if the remaining energy is greater than the current round's energy; otherwise, it will be assigned as a member node. This would save the network from being too exhausted too quickly.

The rest of the paper is organized as follows: The required background and related work are presented in Section 2. In Section 3, we discuss our suggested system model and algorithm. The simulation results and analyses are discussed in Section 4. Finally, the paper is concluded in Section 5.

Related Work

One of the major challenges of the IoT systems is the cost of servicing and maintaining a huge number of sensors [6]. Further replacing sensor batteries that are already in the network field might be a time-consuming task [7]. For some applications, the sensors must be deployed in a field without requiring any human. This leads to yet another significant challenge which is the power management. The reliable end-to-end data transmission, effective congestion control, and the low packet loss ratio are also major concerns in WSN [8].

Any WSN-assisted IoT application's primary goal is to route and transfer data acquired from sensors to the BS. Wireless sensor network routing techniques are divided into two categories: (i) probabilistic protocols, and (ii) non-probabilistic protocols.

In probability-based clustered routing protocols, each member node is described by a retransmission probability function indicating with what probability a node will forward a received message to all of its neighbors. The probability assigned to sensor nodes is used as the main indicator for CH selection. Heinzelman et al. [9] propose the Low Energy Adaptive Cluster Hierarchical (LEACH) routing system, which is a well-known cluster-centered routing protocol. In LEACH, the energy level of the current CH is examined after each round, and if it is drained and below the threshold value, a new CH is selected using probability theory. The CH's tasks will be rotated or shared among the network's sensor nodes. This rotation of CH responsibility keeps network node energy consumption stable, ensuring that no node is overloaded. LEACH confronts a number of challenges, including a limitation of scalability for large network sectors. In [10], the authors introduced the Stable Election Protocol clustering technique (SEP). In SEP, authors introduced the concepts of “Normal Nodes” and “Advanced Nodes” in wireless sensor network. Advanced Nodes” are nodes that have more initial energy when deployed the network. Only "Advanced Nodes" are capable of acting as CHs, whereas Normal Nodes can act as relay nodes or send their own data, but they cannot perform the role of data aggregation, which is reserved for CHs. The CH is chosen based on the sensor nodes' remaining energy. It is not necessary to have global knowledge of the nodes' residual energy to select the CH after every round. Akyildiz et al. [11] present the Hybrid Energy Efficient Distributed Computing (HEED) Protocol in order to improve the balance of energy consumption among different parts of the sensor network. The main parameters for CH selection in the HEED technique are residual energy and node density. The HEED protocol is based on three main parameters: distribution of energy consumption to increase network lifetime, selection of CH to be terminated after a fixed or pre-defined number of iterations, and the access to CHs.

Since the nodes in a sensor network have a limited energy, extending the network lifetime by balancing clusters in the network are critical. The researchers in [12] proposed a weight-centered energy efficient routing protocol that is designed to assure energy efficiency by constructing balanced-sized clusters and optimizing intra-cluster network architecture. By measuring its remaining energy as well as the total number of directly connected neighbors, each sensor node in the network computes its corresponding weight in the network. The CH will be a node with the highest weight in the neighborhood, while the other nodes will be the member nodes. The proposed approach creates multi-layer clusters, with nodes in each cluster transmitting information to the cluster head through other nodes. Therefore, a large quantity of energy is expended in neighbor finding process. As a result, this protocol has the disadvantage of having a very unreliable or stable period.

To improve network stability, the Distributed Energy Balance Clustering (DEBC) Protocol was proposed in [13]. The suggested technique analyzes the residual energy of the sensor node being evaluated for the next round CH with the average energy of the network's remaining nodes to determine the CH for each round. Different energy levels of nodes are distributed at random throughout the target area, and nodes with higher initial energy are more likely to be selected as CH than their low energy counterparts. Because of the cluster's node redundancy, the authors in [14] suggested a routing protocol that separates larger clusters into smaller clusters to save more energy. The mechanism led to fact CHs will be receiving small sizes frames data and a large number of data frames will be received by the BS during that particular time period. In addition, only one redundant node is active and interacting with other nodes, while the others are in sleep mode. Nodes will continue in sleep mode until the energy level of the active node reduce. This method attempted to balance the system's energy consumption thereby extending the network lifetime.

Despite the probabilistic routing algorithms are energy efficient, non-probabilistic routing algorithms presents a well-established research field for WSNs applications. The selection procedure in a non-probabilistic based clustered routing protocol is more particular and is based on numerous parameters like sensor node connectivity, node position, number of neighboring nodes, residual energy and so on. In [15], Thein et al. change the probability of choosing CH based on the residual energy of each node. The proposed method takes into account the optimal value of CH for constant values such as 1 and 6. The network lifetime is increased by 40 - 50% using this strategy. Another CH selection approach for data aggregation that eliminates redundancy and increases network lifetime is discussed in [16]. The threshold value is changed by taking into account a hotness factor, which determines how hot a given sensor node is in comparison with the rest of the network.

In [17], CH is selected using Particle Swarm Optimization (PSO). The selection criteria provide an objective function in terms of intra-cluster distance, node degree, residual energy, and a number of optimal CHs. The model performs better in terms of several network metrics like network lifetime and energy consumption, compared to various routing protocols. PSO-ECHS is explored in [18], where node-to node distance, distance to BS, and residual energy are used to identify PSO-based CHs.

In [19], an enhancement of LEACH protocol was presented, in which residual energy is a key factor in CH election. The suggested method attempts to balance system energy consumption, extend network lifetime, maintain connectivity, and reduce loss rate. H. Farman et al. [20] describe a non-probabilistic multi-criteria-based CH selection in which the network is separated into several zones. The Analytical Network Process (ANP) decision tool is used to choose the CH or zone head. A collection of parameters was gathered from which the best parameters for zone head selection were chosen.

In the recent decade, WSNs have become a vital technology for Internet of Things scenarios. Therefore, all of the above strategies can be employed in WSN-assisted IoT applications. The WSN provides a data collection and communication platform for monitoring and controlling the physical environment [21]. T. M. Behera et al. propose an efficient cluster head selection technique that rotates the CH position among nodes with higher energy level as compared to other [22]. The suggested algorithm considers the initial energy, residual energy, and the optimum value of cluster heads while selecting the next group of CHs. This method is appropriate for IoT applications including environmental monitoring, smart cities, and systems.

To maintain IoT standards updated, researchers have focused on device energy-saving approaches like as clustering, where the CH should be carefully selected. Various strategies for the CH selection that improve network performances were investigated from the above literature. For non-probabilistic protocols, important characteristics like as residual energy, initial energy, and the optimal number of clusters in the network have been addressed for adjusting the threshold value during the CH selection. In this paper, we introduce a novel non-probabilistic clustering algorithm which is suitable for resource-constrained wireless internet-of-things sensor network applications. To select the next group of CHs for the network, the suggested algorithm analyzes initial energy, residual energy, energy of the round, and the optimum value of CHs. Table 1 summarizes the notations used in the rest of the manuscript to analyze these parameters.

Table 1: Summary of the used notations

Notation Meaning	Notation Meaning
CH	Cluster Head
CM	Cluster Member
BS	Base Station
n	Total number of wireless sensor nodes
l	Length of message in Bits
p	Probability to select a node as CH
T(sni)	Threshold function value against ith sensor node
DT	Direct Transmission
TDMA	Time Division Multiple Access
$E_{res}^{r_i}$	Remaining energy level of the node during the i^{th} round
$E_{round}^{r_i}$	Energy will be consumed by the elected CH during the i^{th} round
E_0	Initial assigned energy level
M	Network diameter
m	Number of clusters
K	Optimal number of CHs
ϵ_{fs}	Transmitter amplifier refers to the free space mode
ϵ_{mp}	Transmitter amplifier refers to the multi-path attenuation mode
$E_{processing}$	Energy consumption in local processing
E_{Tx}	Transmitter Electronics
E_{Rx}	Receiver Electronics
E_{elec}	Energy consumption of transmitting l-bit
$d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$	Critical value for dividing the spatial model.
DRN	Death Rate of Nodes
FND	First Node Died
HND	Half of the Nodes Died
SRE	System Residual Energy

LEACH's Background and Overview

LEACH is a basic single-hop clustering procedure that saves a lot of energy when compared to non-clustering approaches [23]. Sensor nodes are grouped to form clusters after they've been installed. Each cluster uses a CH for data aggregation. The protocol is analyzed in each round. Cluster heads are chosen randomly and clusters are generated in real time. Cluster Members have an equal chance of being elected as CH in order to balance energy dissipation. The BS checks the residual energy on a regular basis until the lifetime is over. Each node generates a number at random between the intervals [0,1]. If the number is smaller than a threshold value T(sni) set by equation (2), that node will become a CH for that round.

$$T(sni) = \begin{cases} \frac{P}{1-P*\left(r*mod\left(\frac{1}{P}\right)\right)}; & For\ all\ n\ \text{Ú}\ G \\ 0; & Otherwise \end{cases} \quad (2)$$

The CH rotates for each round based on the electing probability, implying that all nodes in the cluster, regardless of residual energy, have the same chance of being elected as CH. As a result of the equiprobable CH election process, it is possible to elect a CH with small residual energy, which will die out quickly as compared to one with a higher energy level. Therefore, the residual energy of each node, as well as the energy of each round, are included into the CH election probability equation. As a result, nodes with higher energy levels are more likely to become CH. If the elected CH's round energy exceeds the residual energy, the related CH will remain a CH.

The LEACH protocol can be used in both flat and hierarchical routing systems, depending on the application. Flat routing protocols are not suitable for large-scale WSNs-assisted IoT application because they require the maintenance of routing table data and are unable to aggregate sensed data. Hierarchical routing protocols can help overcome this problem to some extent. Direct Transmission (DT) is a hierarchical routing technique that allows data to be transferred directly from the source node to the destination [24]. Therefore, DT uses more power to transfer data to the BS, particularly when the latter is placed far away from the sensing field. The battery life of nodes will quickly degrade, reducing the network's overall lifetime. An enhanced algorithm known as RR-LEACH is presented as a solution to this problem due to weaknesses that are related to a variety of aspects relating to the functioning of the LEACH protocol.

System model

The appropriate routing is required for environment-monitoring applications so that network energy can be used effectively [26]. Data transmission from a correspondent cluster will be halted if a node with lesser residual energy is chosen as CH. Therefore, the end user will be unable to access all of the information required to monitor environmental conditions.

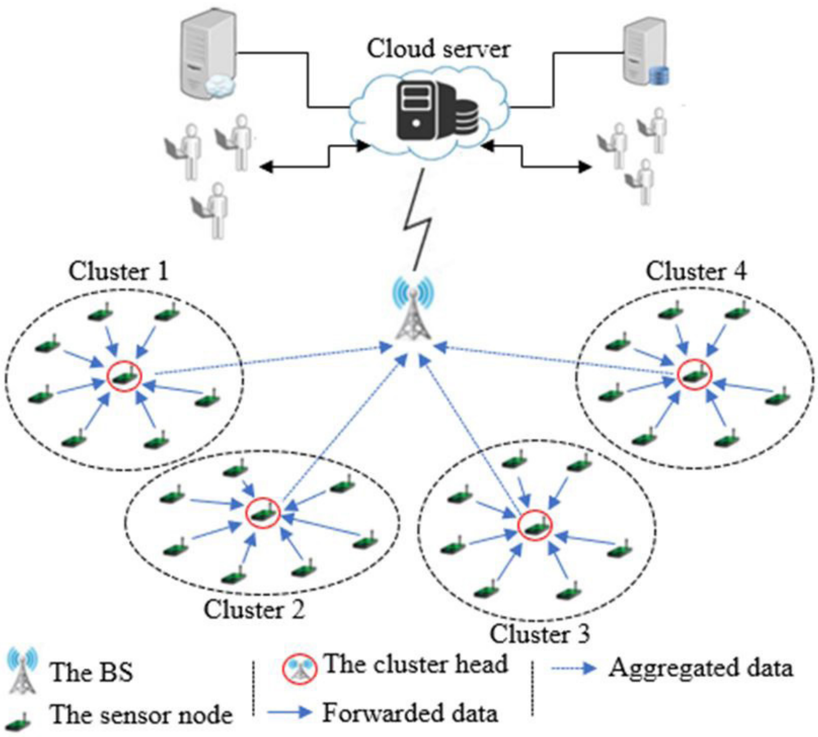


Figure 2: IoT-based environmental monitoring

The communication model shown in Fig. 3 was used to analyze the behavior of the proposed model. The free-space model is used for short-distance communication, such as between member nodes and CHs within the cluster. For longer-distance communication, such as between CHs and the BS, the multi-path fading model is adopted. Based on the energy dissipation model presented in [27], the following equations can be used to calculate the amount of energy required to send and receive l-bit packets:

$$E_{Tx}(l,d)\begin{cases} E_{elec}\times l+\varepsilon_{fs}\times d^2; & d\le d_0 \\ E_{elec}\times l+\varepsilon_{mp}\times d^4; & d> d_0 \end{cases} \quad (1)$$

$$E_{Rx}(l) = E_{elec}\times l$$

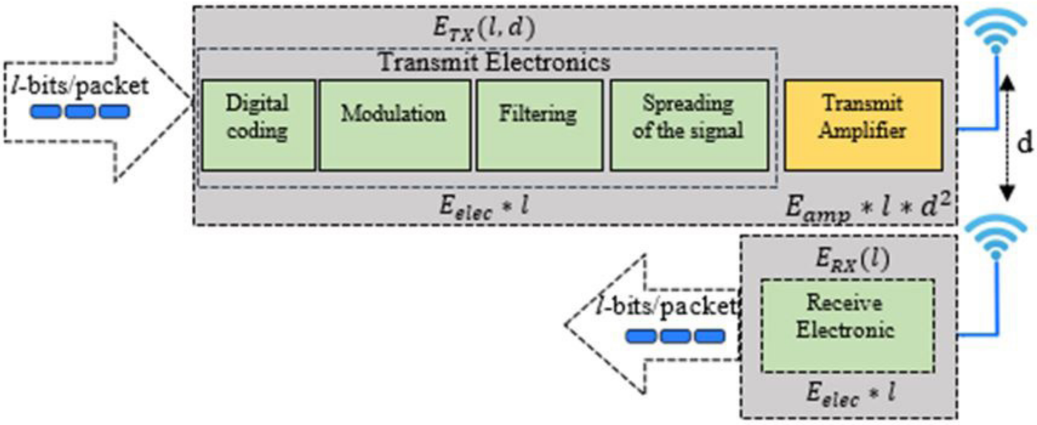


Figure 3: Radio energy model

The proposed RR-LEACH

The proposed approach is intended to solve the LEACH algorithm's as well as direct transmission's restrictions. The RR-LEACH algorithm is based on the LEACH classification technique, which is one of the most widely used. The proposed method uses the CH and the BS with a single-hop communication.

The CH election is based on the residual energy and the current round's energy.

The proposed protocol is a two-stage hierarchical clustering technique that includes setup and steady-state stages. During the initial set-up phase, sensor nodes subdivided into clusters led by a CH responsible for data gathering from member nodes. The data is merged to conserve space by removing redundant bits. The actual data routing occurs during the steady-state stage, when the network's CHs forward the collected data to the BS.

The clusters and CHs are formed in the first round of the setup stage using the conventional LEACH method. Each node in the network dissipates a certain amount of energy during data transport, which varies from node to node. The quantity of energy expended is related to the distance between the sending and receiving nodes. Therefore, for the next round, the CH is chosen using a modified equation as follows:

$$T(sni)=\begin{cases} \alpha * \left(\dfrac{p}{1-p\left(r \bmod \frac{1}{p}\right)}\right) * (1-\beta) * K_{opt};\ n \in G \\ 0;\ Otherwise \end{cases} \quad (3)$$

Where;

$$\alpha = \frac{E_{res}^{r_i}}{E_0} \ and\ \beta = \frac{E_{round}^{r_i}}{E_{res}}.$$

The optimal number of clusters k_{opt} can be written as [28].

$$K_{opt} = \frac{\sqrt{n}}{2\pi}\sqrt{\frac{E_{fs}}{E_{amp}d^4(2m-1)E_0-mE_{DA}}}\ M \quad (4)$$

It is necessary to check the residual power of elected CHs after each round. Each CH can either stay as a CH or become a cluster member node, depending on the residual energy. The residual energy for each CH is determined using the following equation:

$$E_{res}(\mathrm{CH}) = E_0(\mathrm{CH}) - (E_{Tx}(\mathrm{CH}) + E_{Rx}(\mathrm{CH}) + E_{processing}(CH)). \quad (5)$$

Each member cluster node transmits a l-bits message to the CH during each round, resulting in the total energy wasted in the network during a round being described as:

$$E_{round} = KE_{cluster} = l(2nE_{elec} + nE_{DA} + k\varepsilon_{mp}d_{toBS}^4 + n\varepsilon_{fs}d_{toCH}^2 \quad (6)$$

For i=1, $\frac{E^{r_1}_{round}}{E_{res}}$ is set to 0 because there is no need to consider the energy of round in the first round. As a result, during this round, just simple LEACH is used. For the subsequent rounds, the number of rounds $r_i \forall_{i\in\{1,\ldots,max\}}$ increases, β increases, and (1 - β) decreases, balancing the weight between the percentage and residual energy required to select CHs. The proposed model adopts the concept of clustering and the periodic checking of the energy levels in each round, which increases the network reliability. Therefore, this protocol can not only extend the network lifetime, but can also balance energy between sensor nodes. The entire process is depicted as a flowchart in Fig. 5.

Once the CHs for the current round have been chosen, they send information about their CH announcements to member nodes in their clusters. The sensing nodes evaluate the request message's signal strength before deciding which CHs to join. To avoid data collisions, the CH broadcasts the Time Division Multiple Access (TDMA) schedules for the member nodes to send data in different time slots. The process is repeated for the remaining rounds until all of the nodes in the network have been using up all of their energy.

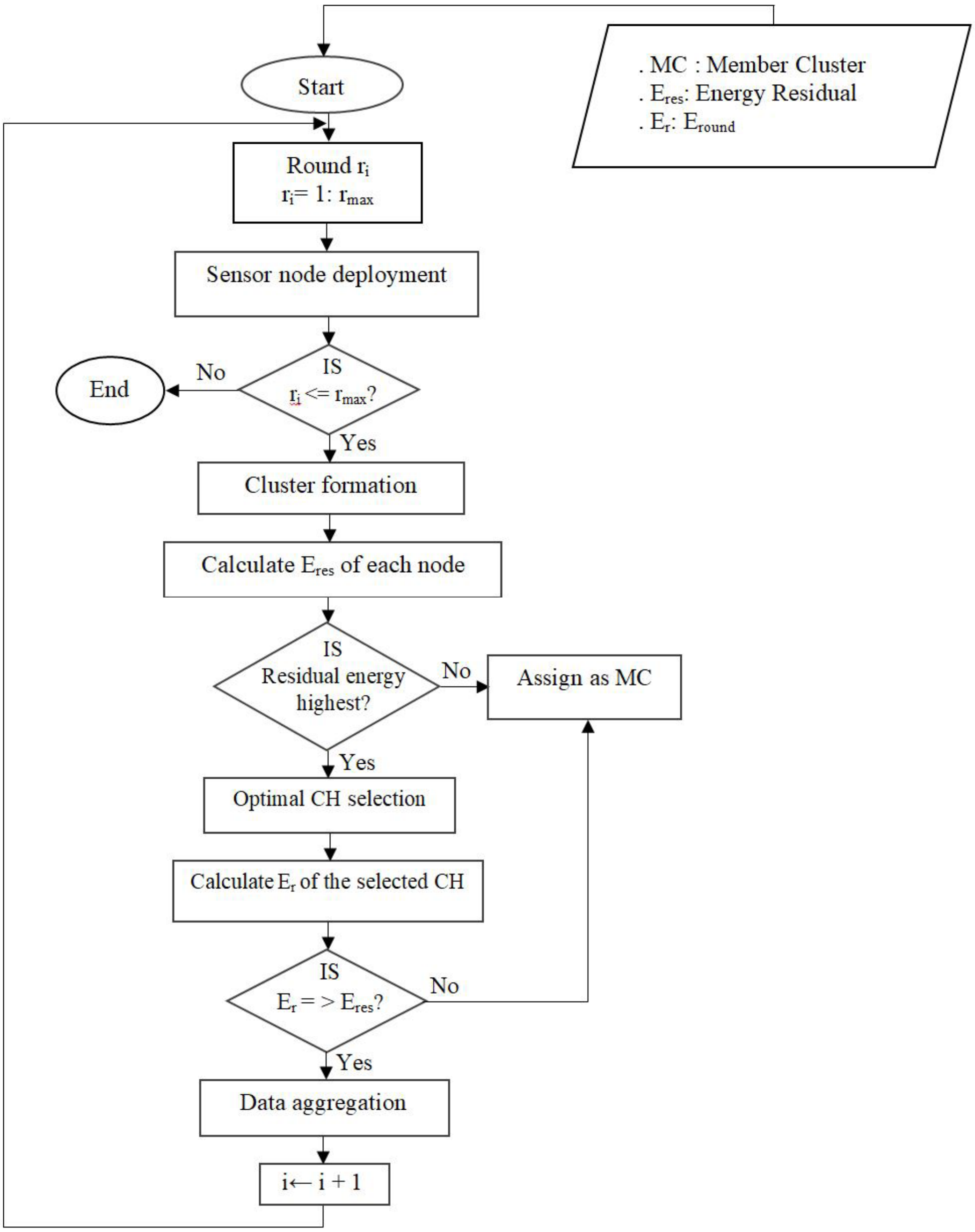


Figure 5: Flowchart of RR-LEACH

Data is transmitted to CHs during the steady-state stage during the time slot allocated to each node. The CH will begin processing the data after all of the nodes in the cluster have finished sending data. The CH receives data, then aggregates it to remove redundancy and compresses it as much as possible to improve the bandwidth utilization. According to the specified application, the data is subsequently sent to the BS via single-hop or multi-hop transmission.

Simulation Results and Discussion

The proposed RR-LEACH and comparative algorithms are analyzed using Matlab based on the network characteristics shown in Table 2. The simulation parameters are similar to those used in numerous point-of-care studies on this topic. The network lifetime, the NDR (Node Death Rate), Average Residual Energy and the packets sent to BS are the most commonly used performance metrics. The NDR is measured by determining the First Node Death rate (FND), Half of Nodes Death rate (HND), 75% of Nodes Death rate and Last of Nodes Death rate.

Table 2: Simulation parameters of sensor network

Parameters	Value
Sensing Area	100 × 100 m^2,
Node Density (n)	100
Initial Energy of each node (E_0)	0.25J, 0.5J, 1.0J
Energy dissipation: receiving (E_{amp})	0.0013 pJ/bit/m^4
Energy dissipation: free space model (E_{fs})	10 pJ/bit/m^2
Energy dissipation: power amplifier (E_{amp})	100 pJ/bit/m^2
Energy dissipation: aggregation (E_{DA})	5 nJ/bit
Data Packet Length (Bits)	2000, 4000

Analyze the network's performance

The simulation result in Figs.6 and 7 shows the achieved network lifetime and NDR by DT, LEACH and RR-LEACH. RR-LEACH outperforms the other two protocols, as seen by the plotted results. In DT, the source node directly transmits its data to the BS, consuming more transmit power. As a result, the death rate of nodes in DT is substantially higher, resulting in a much shorter network lifetime. Instead of direct transmission, data is sent via CHs in LEACH; thus, LEACH has a longer lifetime than DT, but the blind CHs selection causes a rapid decline in performance when compared to RR-LEACH. The latter's dominance in terms of network lifetime is largely due to its effective probabilistic CH replacement based on maximum residual energy and sufficient round energy.

As shown in Fig.7, in DT, the last node dies after 1300 rounds, in LEACH after 1530 rounds, and in RR-LEACH after 2440 rounds. For DT, 75% of nodes die after 548 rounds, and the entire network die after 1300 rounds, whereas for LEACH 75% of nodes consume their entire power after 1300 rounds. These results highlight that the death of the last node in RR-LEACH occurs after the death of 1140 of nodes in DT and 37% of nodes in LEACH.

Since the LEACH protocol assumes that CHs expend the same amount of energy for each round, inefficient CH selection occurs, thus reducing the network's lifetime. The RR-LEACH selects CHs based on the residual energy of nodes, energy required to affect the current round, and an optimal number of clusters, allowing the network lifetime to more rounds.

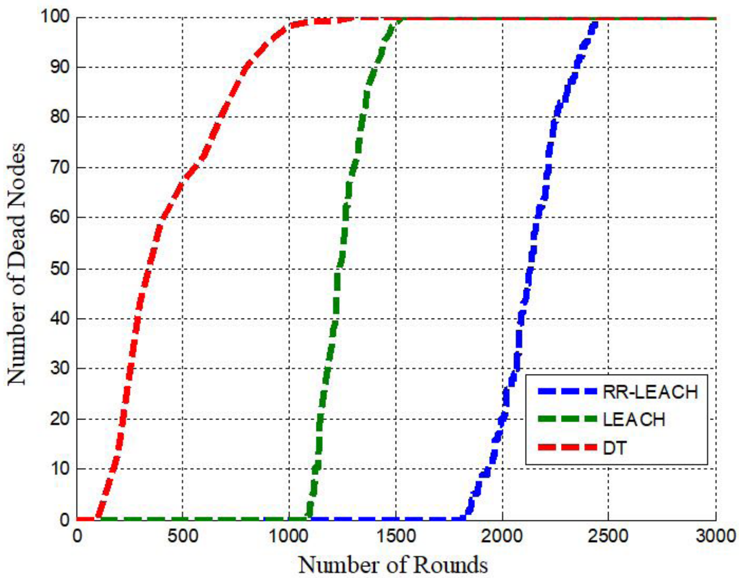


Figure 6: The network lifetime

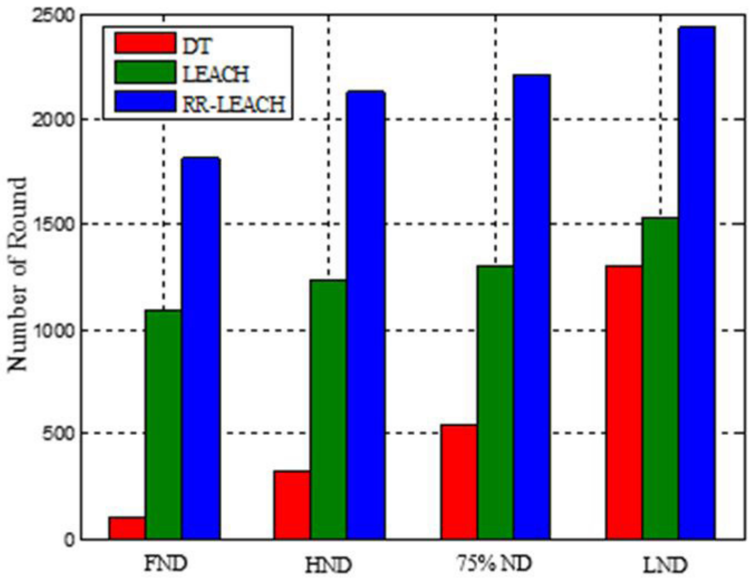


Figure 7: NDR evolution during the network lifetime

Nodes are outfitted with a limited power source in many IoT applications. Therefore, the nodes' energy should be used efficiently to ensure network's long-term sustainability. The influence of the System Residual Energy (SRE) on network performance appears to be important for further analysis of this protocol's effectiveness. Figs. 8 and 9 represent the system residual energy (SRE) and energy consumption evaluation of DT, LEACH and RR-LEACH. As shown in the plotted results, the RR-LEACH outperforms the other two protocols. DT has a fast rate of energy degradation because it does not use intermediary nodes for transmission to the BS. LEACH selects CHs using its own probability function, in which each node has the same chance of becoming a CH, resulting in all nodes dying fast due to the blind CH selection strategy. Due to its CH selection technique that maximizes the network's energy efficiency, the proposed RR-LEACH exhibits a slower decrease as the number of rounds increase than DT and LEACH. Since the energy for RR-LEACH depletes slowly, the network lifetime can be extended to a greater number of rounds.

As illustrated in Fig. 9, DT consumes more energy in fewer rounds followed by LEACH protocol. DT consumed 90% of the total power at 337 rounds, for LEACH, 90% of total power is consumed after 1000 tours, and for RR-LEACH, 1690 tours are required to consume 90% of total power. RR-LEACH performs significantly better than DT and LEACH up to 90%, 50% and 10% of SRE.

For DT, LEACH, and RR-LEACH, the total power is consumed after 1100, 1500, and 2300 rounds, respectively. Therefore, the average energy consumption for the proposed RR-LEACH over DT and LEACH is 52.17% and 34.7% respectively.

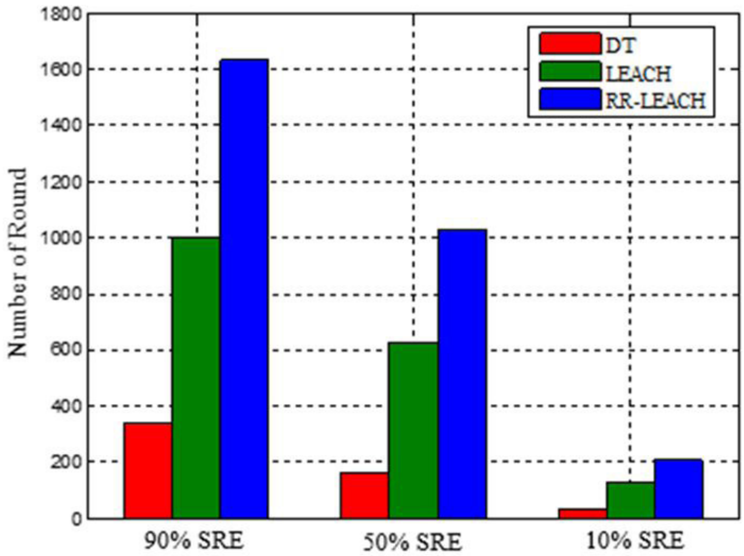


Figure 8: System Residual Energy evaluation

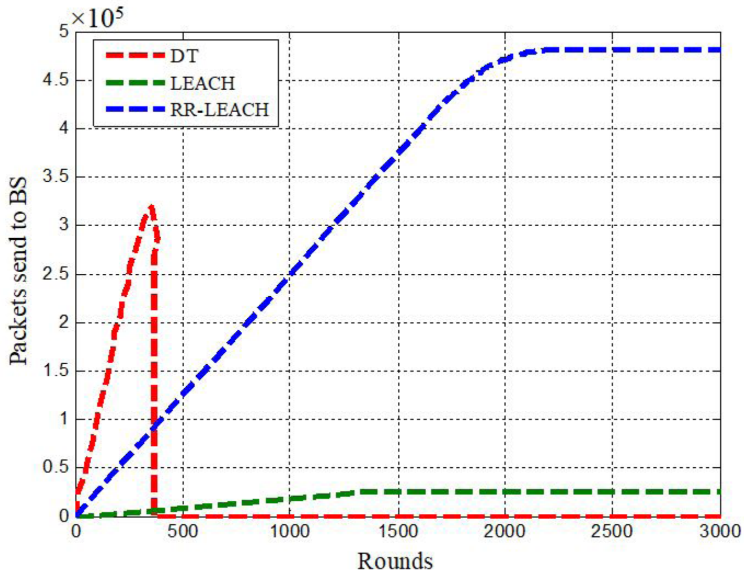


Figure 9: Energy consumption evolution

For IoT applications, the amount of data delivered to the BS is a critical factor. The rate of accuracy of the nodes is defined by the amount of data received by the BS, which is referred to as throughput. The greater the amount of data obtained, the higher the accuracy. The number of packets transmitted to BS by the three protocols is depicted in Fig.10. As we can see, using DT, the network will be decommissioned after 300 rounds. The amount of data generated in LEACH continuously increases until it reaches a stable level after 1500 rounds. The RR-LEACH model is similar to LEACH, however the volume of data created is nearly 94.44% greater. In particular, this method considerably increases the network's information transmission performance. The RR-LEACH protocol enables full connectivity as well as an alternative routing path.

Since the CHs are selected and maintained as a CH based on their residual energies, it effectively guarantees a good network throughput in terms of packets reaching to BS and a proper appropriate operation. The improved performance of network throughput is due to the resilient mechanism of the cluster heads election. Unlike other systems that do not consider important elements like residual energy and the energy of each round. The suggested framework includes an effective threshold value for selecting cluster heads, which improves packet delivery ratio in smart IoT-based WSNs applications.

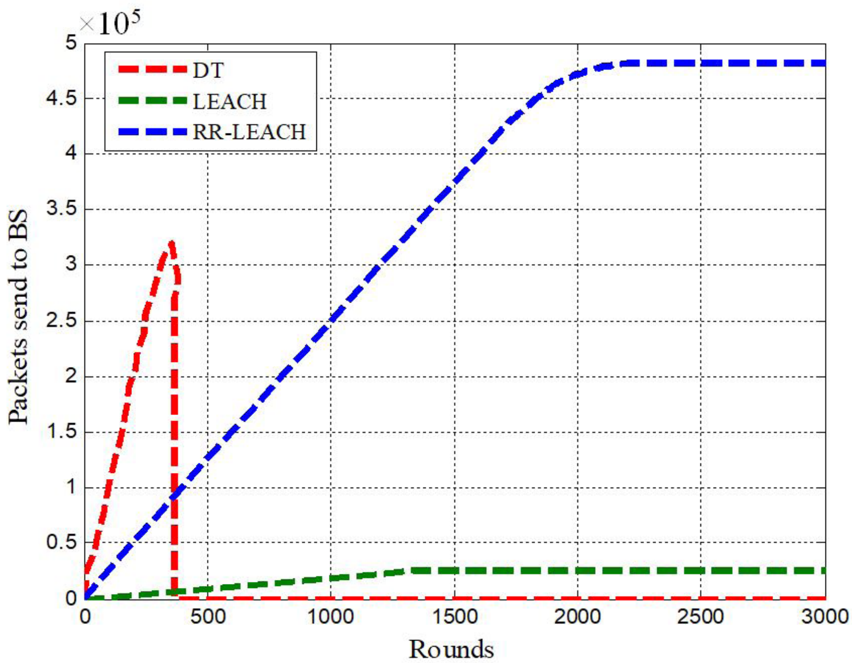


Figure 10: Packets sent to BS

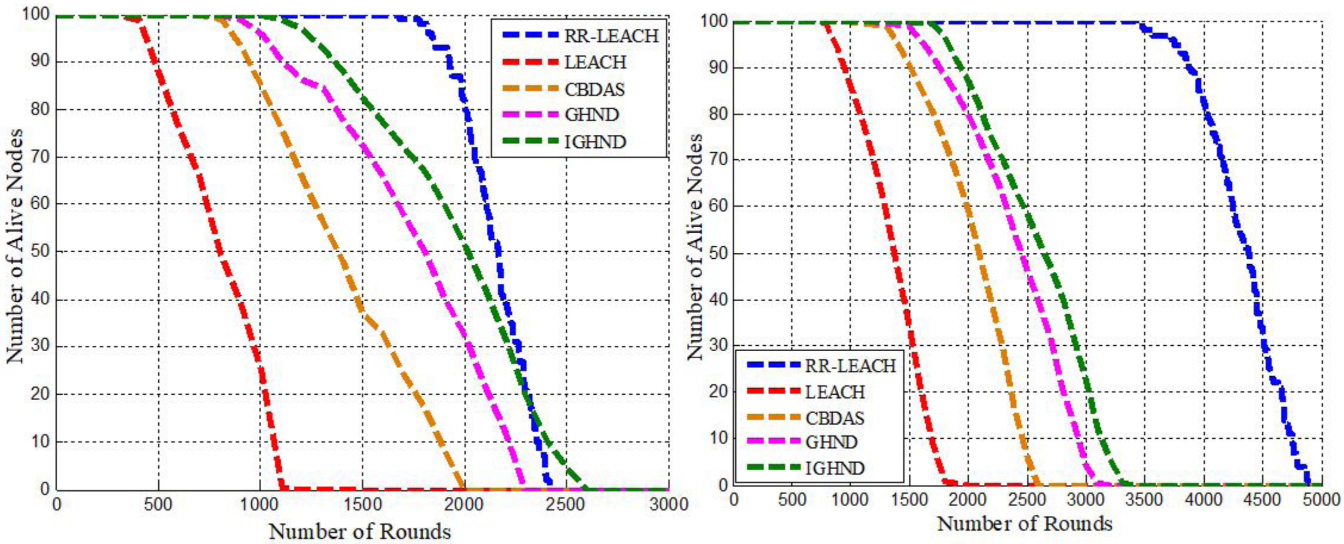
Impact of energy on Network metrics

Network Stability and Network Lifetime are two critical parameters for ensuring good network performance in IoT-based WSNs applications. The time interval between the start of network operation and the death of the first node (FND) is known as network stability. To study the behavior of the proposed RR-LEACH protocol, we analyze and evaluate the network stability and overall network lifetime. For a fair comparison with methodologies proposed for WSN based -IoT applications, such as IGHND [29], GHND [30], and CBDAS [31], we adopt a packet size of 2000. Network permanence's are measured in terms of number of rounds by considering different initial energy 0.25J, 0.5J and 1.0J.

Given that the network lifetime is defined as the time from the beginning of the network till the death of the Last node (LND). As illustrated in Fig.11, the proposed algorithm is compared to existing protocols in terms of network lifetime by taking into account different initial energies of 0.25J, 0.5J, and 1.0J. Both IGHND and RR-LEACH perform similarly at 0.25J starting energy, however there is a significant difference at 0.5J and 1J, for the following reasons. Eq. (3) is proposed by the product of two terms, including the percentage, the remaining energy ratio with different coefficients α and (1 – β) and the number of optimal CHs. When E_0 is low, α and (1 - β) reduce quickly during the network lifetime. Therefore, the CH selection decision's balance is less important. For quite high initial energies, the proposed algorithm proved to work well.

For an initial energy of 0.5J, the RR-LEACH, IGHND, GHND, CBDAS, and LEACH protocols have network lifetime of 4887, 3400, 3200, 2600, and 2000 rounds, respectively. Considering the initial energy of 1J, 100% depletion of sensor nodes occurs after about 9700 rounds in RR-LEACH. For IGHND, GHND, CBDAS, and LEACH these values are 4500, 4000, 3500, and 2000 respectively. Therefore, using 0.5J, the suggested RR-LEACH algorithm extends network lifetime by 30.42%, 34.5%, 46.79%, and 59%, over the IGHND, GHND, CBDAS, and LEACH algorithms, respectively. Applying 1.0J, the proposed algorithm has better performance in IoT applications with the advantage of boosting the wireless network lifetime by 53.6%, 58.76%, 63.91% and 79.38%, compared to IGHND, GHND, CBDAS, and LEACH, respectively.

According to NDR evolution during the network lifetime, the network stability of RR-LEACH outperforms LEACH, CBDAS, GHND and IGHND by 76.19%, 51.84%, 46.42% and 40.47% respectively for an initial energy of 0.25J. Considering 0.5J, the RR-LEACH algorithm is 77.19%, 64.91%, 57.9%, and 50.29%, superior to LEACH, CBDAS, GHND, and IGHND algorithms respectively. For 1.0J the proposed RR-LEACH algorithm improves the network stability by 85%, 67.6%, 62%, and 57.75% than the LEACH, CBDAS, GHND, and IGHND algorithms, respectively. Furthermore, the proposed RR-LEACH method outperformed all other algorithms in terms of the death of the half node (HND) in various energy levels.



(a) Initial energy of 0.25J (b) Initial energy of 0.5J

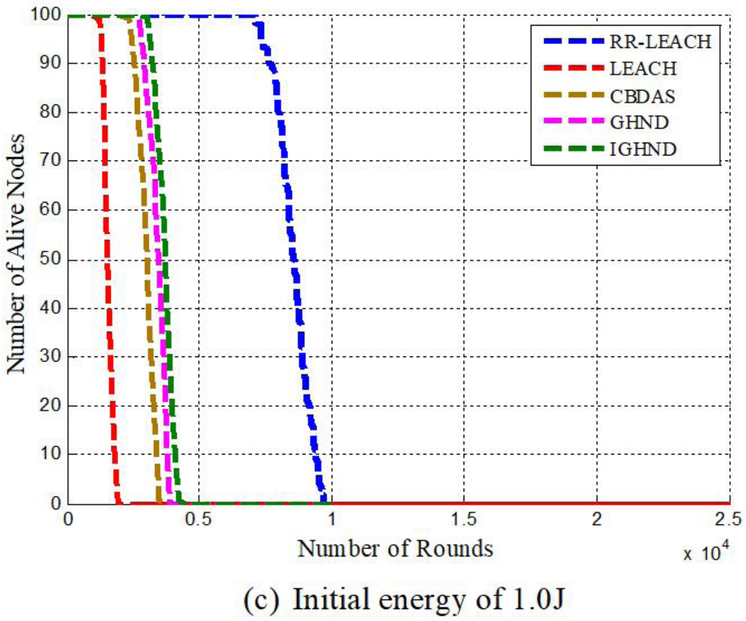


Figure 11: The achieved lifetime for varying initial energy: Number of alive nodes vs. number of rounds. Energy initial of (a) 0.25J; (b) 0.5J; (c) 1.0J

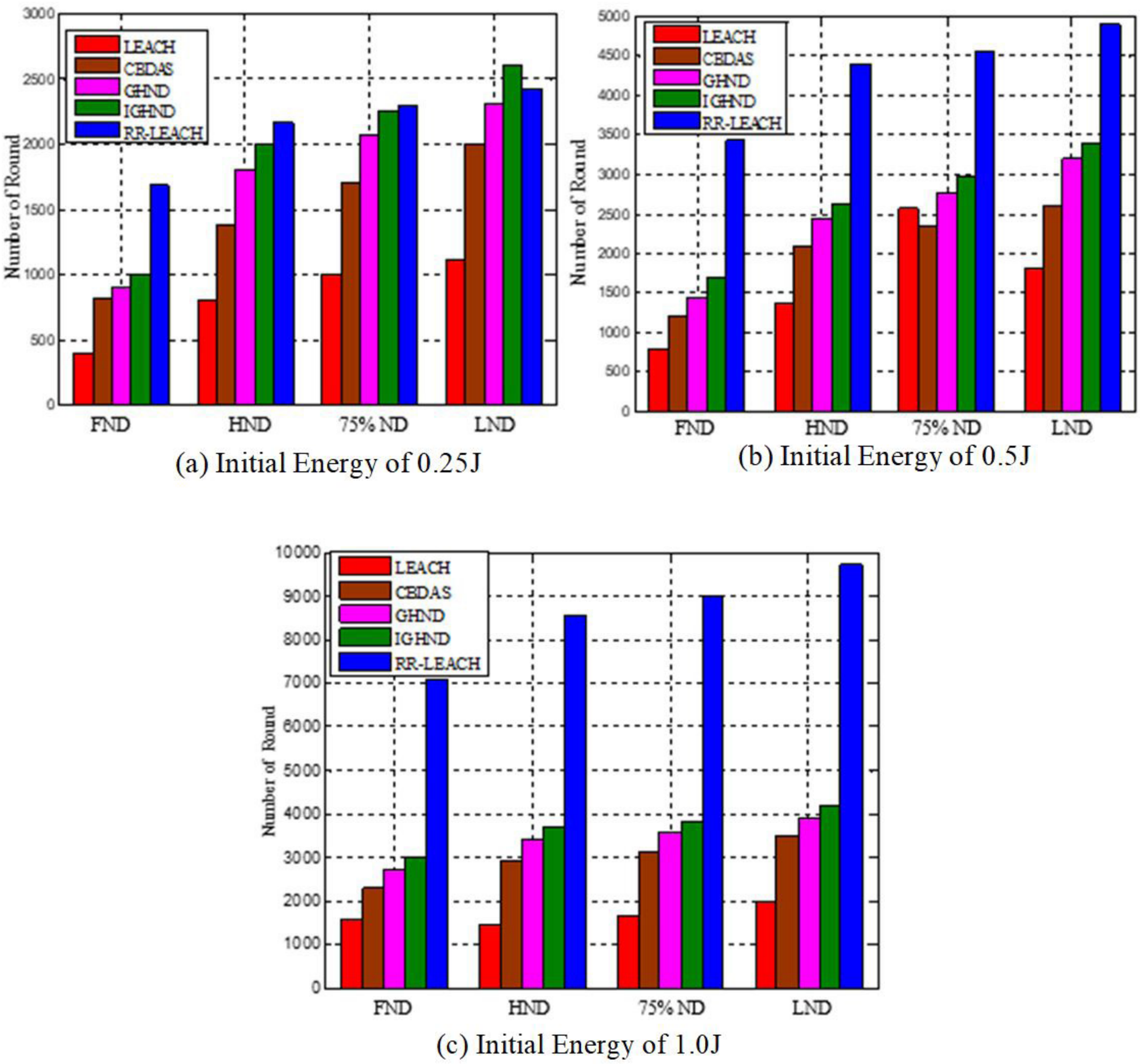


Figure 12: NDR evolution during the network lifetime under varying initial energy. Initial energy of (a) 0.25J, (b) 0.5J, (c) 1.0J

Conclusion

In this paper, a resilient routing algorithm named RR-LEACH was proposed to make WSNs more sustainable and optimize their operation in many IoT-based smart applications. The suggested protocol was aimed to address the constraints of LEACH by introducing probabilistic cluster head selection based on residual energy and regular round energy evaluation. The RR-LEACH protocol is based on the clustering topology. According to the results of the performance evaluation, RR-LEACH outperforms DT, LEACH, CBDAS, GHND, IGHND, in terms of network lifetime, network stability, node death rate speed, and residual energy depletion speed, as well as traffic load generated on the network.

We intend to expand our work in the future by adopting a security aspect that protects against all forms of attacks, including wormhole, denial-of-service, and black hole attacks, in order to prevent illegal access from the outside world.

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