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Improved smart energy-based routing approach for IoT networks in wireless sensor nodes

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Abstract

An emerging communication and network domain called the Internet of Things (IoT) uses nodes that function like actual real-world objects. Both moving and fixed nodes are possible for these. Maintaining node stability or improving inter-node connectivity is the main task for every IoT network. These networks are portable, leading to an overwhelming production of control overhead transmissions which can be reduced with the help of network clustering. In order to extend the network's lifespan, it is therefore necessary to improve the power usage of sensor nodes. The goal of this research work is to improve network lifetime, increase throughput, reduce packet latency or packet loss, and even expand to addressing threatening nodes in order to cope with the issues of IoT-based sensor systems. The proposed Improved Smart Energy-Based Routing Protocol (ISERP), once combined with a wireless energy harvesting (WEH) unit, improves the node's lifespan, the network's quality of services (QoS) amid higher unequal congestion, and those aspects controlling its availability of energy. In the framework of distributed IoT, this protocol meets the standards of QoS through employing hardware-based link quality estimation and accomplishing very high efficiency in terms of energy in comparison with existing routing methods. The sink node chooses both the cluster head (CH) and cluster gateway (CG) by considering the estimation of its cost function. Simulation findings indicate that this proposed technique exhibits more network longevity along with lower consumption of energy compared with other existing cluster-based routing algorithms. Specifically, with the proposed ISERP, CHs use 33% less energy in comparison to existing techniques, and 40% of all nodes remain active until the end of the phase.

Keywords: Energy efficiency, Internet of Things, QoS, Routing, Sensor nodes, Wireless harvesting energy

Introduction

Wireless sensor nodes-based IoT networks are built on top of sensors, meaning that act as IoT's senses and perceptions. While nearly every component of the IoT, whether software or hardware-based, is significant, sensors remain by far the most critical component. All sensor nodes' primary parts are a processor that performs various computing tasks, a transceiver that is used for transmitting and receiving information, a sensing or

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recognizing device made up of a sensor and an ADC, as well as an energy unit just for giving the sensor node its source of power. The computational power, energy, memory, and storage requirements of these nodes are restricted in a number of ways that are not found in established wireless networks. These nodes function as a transmit as well as the initial node. The data becomes susceptible to unwanted access as an outcome of misconfigured nodes [1]. WSN as well as IoT applications have the potential to cover multiple application sectors, such as massive data-powered applications, by the introduction of 5G networks. The advancement of miniature detectors as well as actuators along with widely accessible rapid internet connections is largely responsible for the quick development seen in WSN-assisted IoT networks. Another factor contributing to this progress is the widespread adoption of smart devices across various application regions, including sensing as well as data recording using fog or cloud-based platforms [2]. Delivering packets to their destinations successfully, reliably, and with the least amount of overhead remains a difficult task for scholars. As with every kind of communication network, routing has continually been essential. When estimating the cost function (CF) during routing, the amount of energy usage, remaining energy, along with overall energy cost always serve as essential measures and considerations [3, 4]. The network lifespan becomes shorter when the node constantly maximizes its energy usage. Finding the most efficient technique is therefore essential for reducing transmitting delay as well as extending the life of the network [5]. In order to extend the lifespan of networks, algorithms for routing must carry out its routing tasks such as entire packet-based transmission in a highly efficient way. IoT networks use a variety of devices. Starting energy, use of energy, remaining energy, linking resources, recognizing capability, along with communication distance, all contribute to the heterogeneity or diversity. The degree of flexibility needed in diverse IoT networks cannot actually be accommodated by homogeneous network standard routing techniques. That is why it becomes important to create protocols for routing for IoT networks based on heterogeneous WSNs [6]. Widespread implementation of IoT networks as well as devices depends on the availability of energy and efficient use of energy (or energy efficiency, or EE) [7]. A number of protocols for routing are being offered by the IoT networks, including positioning-based routing algorithms, reactive, cluster-based (CBR), proactive as well as geographic-based techniques [8].

In current systems, several routing methods were developed to boost network efficiency as well as expansion in terms of both latency and overall consumption. Because the IoT's framework is complex as well as reactive during an unsteady wireless condition, existing algorithms cannot be the best choice for applications involving the IoT. IoT system development faces obstacles by multiple data and network security issues that arise as a result of the fast deployment of these systems [9]. Aggregation of data and transmission strategies can generally be classified into two categories [10]. The initial method uses partial data to perform data analysis meanwhile receiving the data from sensors without requiring a specific structure. Sensor nodes are able to observe data in order to send it to the base station (or sink node, or SN) [11, 12], other than this aspect uses a greater amount of energy or causes the node to fail before its time, which causes new network problems like the network hole issue [13]. A structure, or framework process, which is the second, divides a network's area among a number of clusters. Under every domain, there is one unique data-assembler node that collects information across each of that area's linked nodes and performs clustering steps. After that, it utilizes a standard communicating route to transfer the aggregated information to its SN or central station (CS). In the majority of WSN systems, sensor nodes perform separately and have been exposed to a number of security issues. The development of inexpensive, small-sized, IoT-enabled sensor networks has made a possibility to add intelligence towards small-scale to a large-scale device [14].

It is possible to optimize the energy consumption of the sensor nodes via clustering. The principle of clustering involves grouping nodes which are close to one another or that perform comparable tasks. A cluster is composed of a couple of kinds of nodes: member nodes (MN) along with cluster head (CH) nodes. MNs collect data from their surroundings and then forward it to the CH. Furthermore, data is gathered, shortened, and then transmitted to a sink node via CHs. Both one-way and multi-hop communication among the CH and SN are feasible. MNs consume less energy than CHs on average. To keep the total network energy expenditure constant and increase the network's longevity, the CH duty needs to be switched around network nodes [15]. Protection against harmful nodes is a crucial component of WSN. Weaknesses in the routing techniques of WSNs include attacks like hello flooding, black hole, wormhole, and Sybil, with selectively forward [16–18]. WSNs require dependable, efficient, as well robust routing algorithms to deal with all of these threats.

Related work

To extend the lifetime and dependability of WSN-assisted IoT networks, numerous methods are put out in the existing literature, according to Table 1. Most of these are wireless transmitters or sinks, optimized node implementation, harvesting energy, the beamforming process, clustering or routing, communication dependence, along with different optimum approaches [19].

To eliminate the hot spot issue by extending the network's lifetime in WSNs, both fuzzy logic-based uneven clustering routing hybrids (FUCARH) and ant colony optimization (ACO)-based routing techniques have been implemented by Arjunan S. et al. [20]. Active and reacting data transmission is facilitated by the hybrid nature of this existing model, which is an uneven clustering procedure. This existing work can be extended for the network with mobile nodes and multiple sinks, with additional parameters such as link quality and coverage redundancy.

Another compact cluster-building approach called Artificial Bee Colony-SD (ABC-SD) is modeled by Ari AAA. et al. [21] after the quick and effective pursuit of artificial bee colonies (ABC). The basic ABC approach is expanded upon by this method. It outlines a novel cluster balancing algorithm which balances the energy amount of the sensor against the transmission link's efficiency, whereas the routing way that is selected has fewer hop counts or is cost-effective when it comes to energy usage. Later, this work can be extended for both cellular BS and sensor mobility along with TDMA frame layout in the circumstance of changing packet size.

Beyond that, an improved three-layer hybrid cluster method (ETLHCM) by Faizan UM. et al. [22] within a basic, homogeneous, small-scale network attempted to restrict inefficient activities during each cycle, particularly with regard to CH's selection. This

Table 1 Qualitative analysis of various routing protocols

Protocol	Used technique	Advantages	Parameters	Limitations
Optimal cluster-based routing (optimal-CBR) (Jothikumar et al. 2021)	Optimal cluster-based routing and k-means algorithm	Energy distribution, maximum transmission, prolonged network lifespan	Energy dissipation, packet delivery ratio, end-to-end delay	Security mechanism in the implementation
A C-LMS prediction algorithm for rechargeable sensor networks (MA et al. 2020)	Correlation least mean square (C-LMS) prediction model	Significantly improved prediction accuracy, low complexity, and predicting charging can increase the network's lifetime	Network lifetime and data throughput	Practical application schemes of solar charging sensor networks or EH-WSN
Enhanced three-layer hybrid clustering mechanism (ETLHCM) (Ullah et al. 2019)	Hybrid hierarchical clustering approach (HHCA) and distributed approach	Low control message overhead, balanced energy consumption	Residual energy, distance to BS	Proposed mechanism in some application-specific heterogeneous networks and tested it for large-scale networks
Geographic energy-aware routing and Inspecting Node (GIN) (Ai et al. 2018)	Directed diffusion routing, greedy perimeter stateless routing (GPSR), and the inspecting node mechanism	Supports scalability, link quality measurement (RSS), malicious node detection, reducing transmission consumption	Transmission delay, loss packet ratio, and throughput	Work on the application of the proposed protocol in multiple scenarios
Energy-centric cluster-based routing (ECCR) (Hosen and Cho 2018)	Efficient cluster head selection scheme and static clustering	The optimal number of CHs in the network enhances a significant improvement in network lifetime	The steady-state and network lifetime, total residual energy	Designed for the generation and analysis of big data
Energy-efficient compressive sensing-based clustering routing (EECSR) (Wang et al. 2018)	Clustering strategy integrated with the compressive sensing-based (CS-based) theory scheme, backup cluster head (BCH)	Optimal cluster size improves the energy efficiency and extends the network lifespan	Reduction ratio of transmission, network lifetime, and the throughput	Predictive coding can also be integrated with the CS theory to reduce the energy consumption or achieve high energy efficiency
Energy-aware multi-hop routing (EAMR) (Cengiz and Dag. 2018)	Distributed dynamic cluster head selection scheme for energy-efficient routing protocol	Reduction of the excessive overhead, increased scalability, decreasing the effective transmission distances with relay nodes	Network lifetime, network energy dissipation and the amount of data transmitted to the base station	Large-sized WSN or heterogeneous node type in the implementation
Fuzzy logic-based unequal clustering and ant colony optimization (ACO)-based routing hybrid (FUCARH) (Arjunan and Sujatha 2017)	Fuzzy logic-based unequal clustering, ant colony optimization (ACO) based routing, and hybrid protocol	Transmits data in a hybrid manner, load balancing and enhances network lifetime, eliminates hot spot problem	Average energy consumption, network lifetime	Extended for the network with mobile nodes and multiple sinks, with additional parameters such as link quality, coverage redundancy
Unequal clustering scheme based LEACH for wireless sensor networks (Ren et al. 2010)	Improved LEACH protocol, distance matrix created to modify transmission power, distance and residual energy to CS considered for CH election	Enhance the stability of network and prolong network lifetime, good load balancing, does not support fault tolerance	Network lifetime	Complexity issues in implementation

approach distributes node energy among levels of energy (El), which are additionally utilized to balance sensor node energy usage. It will be designed and tested for huge-scale networks in the near term and is going to be used in various applications related to networks that are diverse.

Through the use of static clustering along with fewer CH modifications, the energy awareness multi-hop routing (EAMR) minimizes excessive cost in LEACH which was developed by Lee JS. et al. [23] as well as subsequently developed versions meet the goal. Data transfer, use of energy, along with the longevity of the network all demonstrated important advantages obtained with the EAMR protocol by Cengiz K. et al. [24]. Due to the set cluster sizes, this technique is not suited to huge-scale WSNs.

Getting information to the gateways with the least amount of latency, maximum reliability, with less power usage is the basic objective of all routing techniques. So, motivated by the above research gap of existing algorithms, the objective of this work is to extend the longevity of the network, enhance its throughput, improve the count of operational nodes, minimize packet delay, limit energy usage, and also enhance dealing with harmful nodes. Here, we may reduce the quantity of data delivered to the cluster gateway by aggregating data at the cluster head owing to a reliable/efficient routing technique, which also saves energy or cost. In our proposed routing method, a wireless energy harvesting (WEH) unit is recommended to better optimize the energy lifespan of the network (Table 2). This method aims to enhance the protection of multi-hop cooperating wireless sensing networks against both hardware malfunctions and unwanted entities in which the source or relaying nodes can harvest energy from the signal for data transmission. With the communication system's toolbox in MATLAB R2023b, energy collected and stored through the receiving antenna over various noise channel conditions was simulated.

Energy harvesting techniques for IoT

With the goal of creating sustainable and energy-efficient systems, there is currently a generalized tendency to lessen the environmental effects of technology used in information and communication which also applies to wireless sensors [25]. Outside sources provide energy, and acquired energy is transformed to generate electric power through collecting energy equipment throughout the energy harvesting process. The primary driver behind the expansion of the energy harvesting industry is the replacement of battery-operated power sensors accompanied by rechargeable wireless sensors that rely on energy harvesting (Table 3). The source (the outside energy that is captured or harvested from RF signal), the architecture of harvesting (the systems), and the load (the end user) are the three parts that make up a typical energy harvesting system, that serves to expand the lifespan of the network, and are the straightforward and environmentally friendly methods. For IoT domain applications to prolong, the energy harvester must produce an output power of at least the milliwatt range. When operating sensor nodes continuously without interruption, an energy storage unit is essential. More energy harvesting modules will be implemented as the IoT sector expands, which will lower the price. A number of energy sources are likely to be advised for energy harvesting [26].

One of the main technologies that allow both field-formation WSNs and IoT applications is the energy harvesting (EH) technique [27]. One important aspect

Table 2 Performance comparison of our proposed approach with existing routing protocols

Parameters	Protocol						
	EHARA	**MDDA-EHWSN**	**NEHCP**	**MIMO-UCC**	**IMIMO 5G-based BEE**	**MBMQA**	**Proposed**
N/w lifetime	After an 8000-s period of simulation, the remaining battery level is 50%	Increases based on quality-of-service parameters	71.8%	High	Protect the network from increasing hotspot issues and lengthen the lifespan of the network in the 5G scenario	Maximum	Incredibly high as a result of the integrated WEH unit
Latency	Medium	Low	-	Decrease	Low	Minimal	Very low
N/w stability and security	Maintain the stability	-	Stable region	-	Maintain network stability and support security mechanism	Maintaining network stability	Highly stable and enhances security feature
Average energy consumption	Reduces average consumed energy at each node	Maintain energy-optimized routes by allowing nodes to regain their energy level through energy harvesting	Gives maximum energy efficiency in terms of energy consumption	Consumes less amount of energy using chain schema	Lessen energy utilization or balanced energy depletion	Consume less battery energy or higher energy-efficient network	Minimal cost or consume less energy because of WEH unit
N/w throughput	High	Medium	Maximum	Maximum	High	Enhances	Highest

Table 3 Energy harvesting method's simplification

Energy source	Technology	Power density	Advantages	Disadvantages	Application domains
Solar	PV cell	10–100 mW/cm^2 (outdoor) < 100 µW/cm^2 (indoor)	High-output voltage, Affordable manufacture, Predictable	Unavailable at night, non-controllable	Environment monitoring, healthcare, agriculture
RF	Antenna	0.01–0.1 µW/cm^2 1–10 mW/cm^2	Available anywhere, anytime, predictable, controllable	Distance dependent, low-power density	Environment monitoring
Mechanical vibrations and pressure	Piezoelectric	4–250 µW/cm^3	Powerful density, without an external power source, simplicity in production and design, controllable	Extremely varied results, unpredictable	Infrastructure monitoring, automotive
	Electromagnetic	300–800 µW/cm^3	High-output currents, strongness, affordability, controllable	Generally big sizes are unpredictable	
	Electrostatic	50–100 µW/cm^3	Higher output voltage, comparatively greater output power density, ability to create inexpensive devices, controllable	Necessary bias voltage unpredictable	
Human heat	Piezoelectric pyroelectric	< 35 µW/cm^2	Sustainable and reliable, available, controllable	Low-power density unpredictable	Healthcare
Biomechanical	Electromagnetic piezoelectric triboelectric electrostatic	< 4 µW/cm^3 < 300 µW/cm^3	Available, controllable	Low-power density, unpredictable	Healthcare
Bio	Metal electrodes	Extremely low wattage	Available, controllable	Very low wattage, appropriate for electrical devices on the nanoscale	Environmental sensing in agricultural applications

of deploying big IoT devices is energy harvesting (EH). When deployed, nodes can harvest energy via environmentally friendly sources such as solar, vibration, along with RF electromagnetic energy while employing the EH mechanisms to power up their energy sources throughout their usage. This method greatly improves wireless network reliability while protecting information from monitoring without requiring upper-layer encrypted data. A durable or endless WSN framework may include EH units since they can enable stable battery-less function [28]. When it comes to expanding the node lifespan in reality, the single source of energy layout might not be enough, especially during low-demand times (for proceeding vehicle-based EH) and during the time of night (for solar EH). As such, while creating new EH-aware routing techniques, a novel hybrid structure which links a variety of energy harvesters on a specific node needs to be taken into account [29] Figure 1.

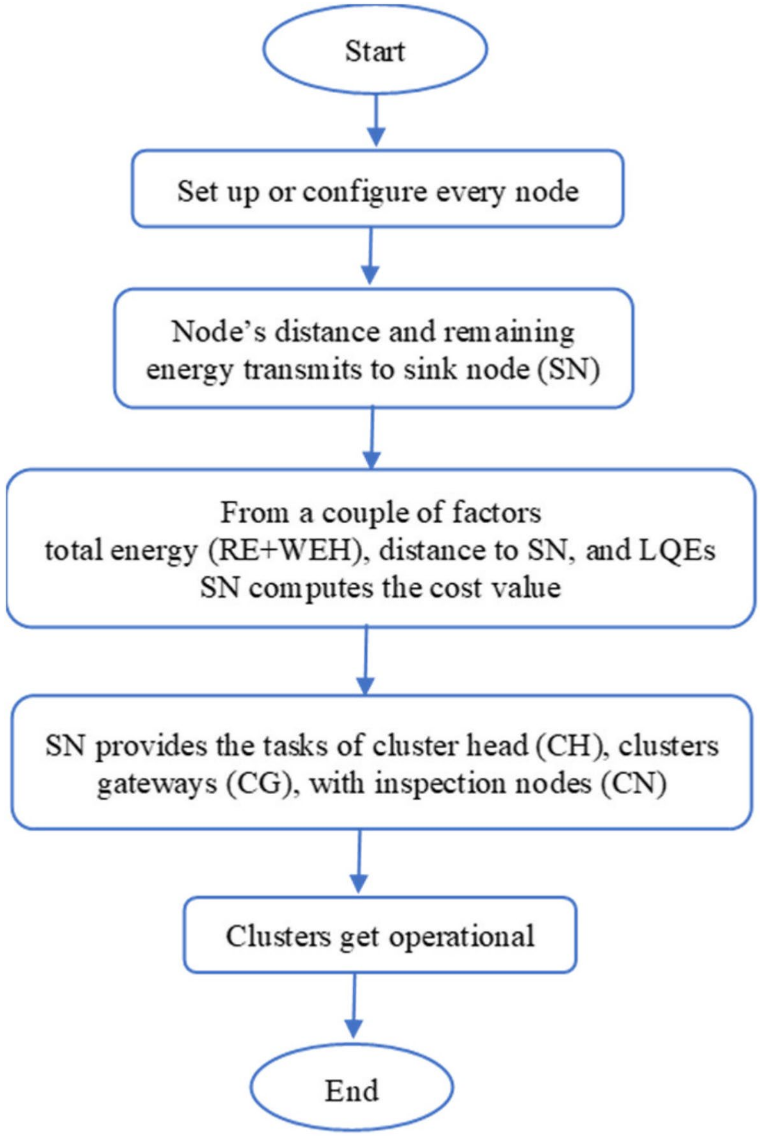

Fig. 1 Workflow of the proposed protocol

In our proposed approach, the "best cooperative mechanism (also known as BCM)" concept is used in the formulation of the WEH [30], which uses time slots to get EH along with broad range allocation. Three kinds of harvesting energy are possible with it; the primary users (PUs) capture energy via surrounding data, the secondary user (SU) receives energy using the PUs, or the SU collects energy through surrounding data, as well. The PUs are not anymore limited in delivering an assigned quantity of information inside a timeslot, in contrast to the current state of the art. Since the WSN-assisted IoT becomes completely application-specific, the usage of energy is taken into consideration during development. Also, an energy-efficient network is one that accurately recognizes all environmental aspects while using an equal value of energy. As a result, it must determine the exact demands while integrating many performance-related factors, including data transfer, packet delivery ratio (PDR), network lifespan, or consumption of energy, in order to achieve energy-saving goals. Hence, the lifespan of the network can be extended through maintaining the network's stability, which eventually relies on the kind of application that sensing nodes continue to perform. Energy savings for such apps have to be accomplished via cutting down on the time/delay it takes to send data for every single energy unit used. Comparably, with certain kinds of applications, network lifetime does not seem as significant as the QoS criteria. To create an improved smart energy-effective IoT network, we choose to point out the energy-saving features and examine the proposed approach using simulations Figure 2.

Proposed system framework

Problem description

- In smart systems, which include efficient energy systems, smart areas, smart houses, smart well-being, with smart agricultural systems, the primary functions of the sensor nodes are to track modifications in both chemical and physical characteristics while transmitting the information to the SN or CS for additional analysis.
- The energy level (EL) requirements as well as the detection abilities of the sensor nodes vary.
- IoT-related technologies or WSN face a number of issues, the most immediate as well significant of which is the usage of energy along with operating costs throughout transmission (or simply the fact that transmission over long distances uses an excessive amount of energy).
- As an outcome, the primary goal of this research project is to minimize the quantity of control data packets used in communication over networks.
- The proposed approach is hierarchical layered and also cluster based in order to maintain the distribution of load and improve a network's lifespan.

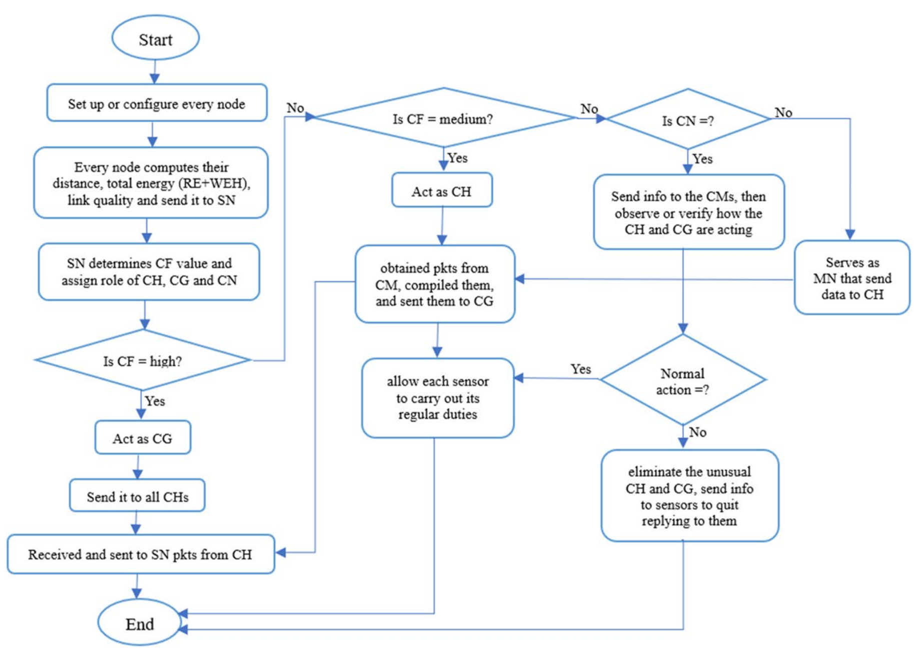

Fig. 2 Functional flowchart of the proposed work

- Direct transmission of real-time data obtained from each sensor node to SN is a complex and energy-intensive process. Therefore, data from sensor nodes is assumed to be sent from cluster members (CM) to the CH, who will then transfer the information to the cluster gateway (CG) and SN with the aggregated information.
- The proposed project implements a check-up node (i.e., CN) that performs safety-relevant operations in order to maintain secure analysis while preventing unauthorized access. It continuously monitors CH and CG.
- An alert for no longer transmitting is put out by CN inside the cluster plus the responsible CH/CG is assigned to block once they fail to deliver beyond a certain quantity of data.
- The present research is based on the WEH unit in order to transform it more efficiently and prepare for future IoT deployment issues. This is why we have put out the "Improved Smart Energy-Based Routing Approach for IoT Networks in Wireless Sensor Nodes (ISERP)" as a modified routing protocol.

Contribution

The following sums up the project's major contributions:

- The three main operations in the design of the proposed ISERP are data clustering, diverse-objective-based CH choice, along with better selection of routes for the delivery of data.
- Each round, the CH selection methodology gets used in an effort to maximize the lifetime of the network along with cost-effectiveness.
- The implementation of a multiple-path network concept is based on the presumption that energy gets used by the transmitter to operate the radio circuitry as well as power amplifiers, alongside the receiver to operate the radio hardware associated with the straightforward model or the wireless transmission/reception model [31].
- SN does the majority of the data processing and even is not limited by capabilities. A crucial function that separates CH from CG is carried out by CF.
- Network longevity and throughput can be enhanced by including WEH units in layered-based clustering formulas. The additional energy causes the liable jobs (i.e., both CHs and CGs) to carry out their allocated tasks to a greater extent.
- Every node has a WEH unit followed by a first-order energy model utilized to calculate how much energy is used throughout information transfer and reception.
- The link performance of the signal-to-noise ratio (SNR), the received signal strength indicator (RSSI), and the link quality indicator (LQI) can be calculated with hardware-powered link quality estimators (LQEs), which are not impeding/delaying the procedure entirely.

To achieve significant energy savings in WSN-assisted IoT networks, hardware-based network performance estimation is essential. Here is a more thorough explanation of how the two are related:

- Link quality estimation, or LQE, is a way to figure out how dependable or high-quality the wireless links are between network nodes. It involves measuring parameters including delay, congestion, packet loss, and signal strength. Network performance can be optimized by nodes using precise LQE to help them decide which communication paths to pursue.
- Reduced overhead: the computational overhead related to link quality estimation can be reduced by using hardware-based LQE.
- Optimal communication: with accurate LQE, nodes can choose the communication channels that use the least amount of energy. Nodes can lessen the requirement for retransmissions and the total amount of energy used during data transmission by avoiding links with high levels of congestion or poor quality.
- Dynamic adaptation: hardware-based LQE facilitates real-time monitoring and adaptation to changing environmental conditions. Based on current knowledge of link quality, nodes can dynamically modify transmission parameters like energy levels, transmission strategies, and routing paths. This adaptability helps optimize energy usage while maintaining reliable communication links.

Network framework

Three rounds comprise the application of the proposed approach: In the first round, when the sensor nodes of heterogeneous type are implemented randomly, they remain stable as well stationary. Also, they communicate to SN about their distance from CM together with their total energy (i.e., residual energy as RE and WEH). To measure this distance, a measurement metric called received signal strength indicator (RSSI) is used. Additionally, SN calculates every installed node's CF in the same iteration. It moves on to the second round on the basis of CF's valuation. Hybrid cluster formation has taken place in this phase. CH, CG, along with CN have made selections according to the computation carried out by CF. With respect to the third-round inter-cluster multi-hop setup, our proposed method guarantees data delivery to the CH members even in the event of a communication channel failure. This is because the suggested approach uses a sub-optimal multi-hop methodology, whereas neighbor nodes in an intra-cluster multi-hop configuration may use quick observing information to investigate one another which means a node is taken as dead by its neighboring node once it fails to reply. Another sensor node that appears within the transmitted matrix via the SN will get information from the neighboring node after it surpasses the dead node. As an example, whenever EL falls below a predetermined threshold, the function of CH, CG, and CN moves to another MN, which is accomplished by determining the CF again plus every node in a sensor network has a WEH unit. Thus, this protocol has significant features such as better load balancing capacity with lower transmission overhead.

Network model

Initially, the total number of nodes represented by N, as 200, are placed across a predetermined $M \times M$ square region to collect ambient information. The following presumption has been used in the development of the proposed approach:

- With varying capacities, sizes, along with competent abilities, these nodes exhibit heterogeneity.
- During the sensing zone, the nodes remain stationary.
- Each node starts out with an equal amount of energy and is rooted with the WEH unit.
- The gap between nodes to SNs is determined using the Euclidean distance equation.
- The technique, time division multiple access (TDMA), is that every single CH utilizes to obtain the data packets via MN, while CG utilizes the same method for getting data by CH.
- The first-order energy model [32] is applied for energy usage during data processing.
- Data is aggregated or constrained by CH and CG in an identical packet before being forwarded.

Methods

Significant data regarding deployed nodes, including Node's identification (ID_n), Remaining or residual energy (also known as RE or $E_{residual}$), Link quality (LQ), as well as Distance (d_{tance}) over SN, are first obtained by SN. Furthermore, the Euclidean equation [27] is going to be applied to determine the distance to SN.

$$d_{tance}(n, SN) = \sqrt{(X_n - X_{SN})^2 + (Y_n - Y_{SN})^2} \tag{1}$$

The distance between n nodes with SN is represented by d_{tance}(n, SN), where X_n and Y_n denote the relevant node coordinates.

Following that during the data sensing stage, all of the sensor nodes are only permitted to become functional to communicate within the time window that it has been assigned. Equation (2) shows that when a node becomes active, it basically determines its $E_{n\text{-}Total}$ or total energy. A predetermined equivalent period of time is used to validate the $E_{n\text{-}Total}$. A sensor node begins observing when $E_{n\text{-}Total}$ is discovered to be higher than the specified Threshold (Th) value; otherwise, simply continues to a further round. Quality is initially verified for the observed data. A specific time, when the data appears significant, the relevant node transmits it straight over to the SN via single-hop transmission with no additional verification; if not, data is forwarded towards the SN via a multi-hop transmission that involves the transmitting node.

$$E_{n-Total} = E_{n-Current} + E_{n-Harvest} \tag{2}$$

Equation (3) appears to be used to define the node's current or remaining energy $E_{n\text{-}Current}$ during time t complying with setup over the time period P_{setup}.

$$E_{Current_i^j}\left(t + P_{setup}\right) = E_{Current_i^j}(t) - E_{round_i^j}(t) + E_{Harvest_i^j}\left(t, P_{setup}\right) \tag{3}$$

Throughout the setup time period P_{setup} round, the energy expended is denoted by $E_{round_i^j}(t)$, whereas during the setup period P_{setup}, the HE is denoted by $E_{Harvest_i^j}\left(t, P_{setup}\right)$.

Energy model The literature has presented a number of different radio models for communication [33]. However, we employ the first-order energy model [32] because of its low complexity as well as applicability to our proposed project. Equation (4) is applied to determine the approximated amount of energy $E_{n\text{-Cons}}$ used (or in sending as $E_{n\text{-Trans}}$, and upon receiving as $E_{n\text{-Recvd}}$ of the data packet)

$$E_{n-Cons} = E_{n-Trans} + E_{n-Recvd} \tag{4}$$

By adding the circuit consumed energy $E_{n\text{-Circut}}$ to the previous Eq. (4), the overall amount of energy used in the amplification, reception, grouping along with data transfer via each sensor node can be calculated. This gives

$$E_{n-Cons} = E_{n-Trans} + E_{n-Recvd} + E_{n-Circuit} \tag{5}$$

Node n used energy $E_{n\text{-Trans}}$ to send data packets of l size across the distance of d.

$$E_{n-Trans}(1, d) = E_{TX-Circuit} \times 1 + E_{Trans-amp}(1, d) = E_{TX-Circuit} \times 1 + \in_{amp} 1d^2 \tag{6}$$

where ϵ_{amp} stands for what kind of radio amplifier.

Also, a node's energy $E_{n\text{-Recvd}}$ was used for receiving sent Pkt,

$$E_{n-Recvd}(1) = E_{RX-Circuit} \times 1 \tag{7}$$

here the energy usage per bit through both the transmitting and reception circuitries is denoted by the terms $E_{TX\text{-circuit}}$ and $E_{RX\text{-circuit}}$, etc.

Furthermore, as stated in Eq. (8), the energy that is expended by a node in sending an entire Pkt is equivalent with the energy expended by that node in receiving that one Pkt.

$$E_{n-Trans} = E_{n-Recvd} \tag{8}$$

As well, the next functionality is implemented to reduce unnecessary functioning and preserve energy.

$$\mathrm{Min} \sum_{i=1}^{\mathrm{Max}} WE\mathrm{cons}(r) \forall r \in R \tag{9}$$

as WE_{cons} stands for the entire amount of energy used, which may be computed by following formula:

$$WE\mathrm{cons} \sum_{j=1}^{N} d0(\mathrm{j}) \times (\mathrm{ETransCntrlPkts} + E\mathrm{n\text{-}RecvdCntrlPkts}) \tag{10}$$

in which the control pkts throughout transfer as well reception via nodes is expressed using $E_{Trans}CntrlP_{kts}$ and $E_{n\text{-}Recvd}CntrlP_{kts,}$ respectively.

Once setup, the proposed approach will take into account the total energy (such as TE) of every single node through the equations outlined as follows:

$$\begin{aligned} &\mathrm{TE} = \mathrm{RE} + \mathrm{HE} \\ &\mathrm{Or,} \quad \mathrm{TE} = \mathrm{CE} + \mathrm{HE} \end{aligned} \tag{11}$$

here CE indicates current energy that can be calculate by Eq. (12) whereas HE denotes harvested energy.

$$\mathrm{RE} = \mathrm{CE} = \mathrm{E}_{\mathrm{Initial}} - \mathrm{E}_{\mathrm{Cons}} \tag{12}$$

The “best cooperative mechanism (also known as BCM)” concept is used in the formulation of the WEH, which uses time-slots to harvest energy while distributing energy in a 5G system [30]. The rest of the equation provides the WEH calculations.

Let R_{pt} or R_{st} reflect, accordingly, the primary user’s (PU) or secondary user’s (SU) throughput in every single time frame. PU’s instant non-cooperative rate of transmission and cooperative rate of transmission over a timeframe are indicated by R_p and R_c. PU’s throughput relies upon these two variables. The EH store ratio (ρ_1) and (ρ_2) of SU from ambient signals and PU signals, as well as the channel power gain to noise power ratio (γ_p) from the PU transmitter or receiver, all have an impact on R_p. One way to use R_p is as:

$$R_p = log_2[1 + (Y_p + \frac{\overline{X_p}(1 - \overline{\rho_1} - \overline{\rho_2})}{\rho_1 + \rho_2})\gamma_p] \tag{13}$$

in which Y_p stands for PU’s energy source ratio, whereas $\bar{X}$p is for its EH ratio during the last period.

R_c is related to the last session’s EH, the channel gain to noise ratio (γ_s) among the transmitters of PU and SU, the communication link’s channel gain to noise ratio (r_p) within the transmitters of SU and PU’s recipient, and the power that SU has been allotted (w_s) for the active transmission. One way to represent R_c is as:

$$\mathrm{R_c} = \frac{1}{2}\min\{\log_2\left[1 + \left(\mathrm{Y_p} + \frac{\overline{\mathrm{X_p}}(1 - \overline{\rho_1} - \overline{\rho_2})}{\rho_1 + \rho_2}\right)\gamma_s\right], \log_2\left[1 + \left(\mathrm{Y_p} + \frac{\overline{\mathrm{X_p}}(1 - \overline{\rho_1} - \overline{\rho_2})}{\rho_1 + \rho_2}\right)\gamma_p + w_s \mathrm{r_p}\right]\} \tag{14}$$

R_s stands for SU’s instant non-cooperative rate of transmission and its EH ratio is represented as X_s via surrounding sources. The SU’s EH ratio (X_{sp}) derived from PU’s signal, and its channel gain-to-noise ratio (r_s) among the transmitter and receiver are all connected with R_s that can be represented as:

$$R_s = \log_2\left[1 + \left(\frac{X_s\rho_1 + X_{sp}\rho_2 - 2\rho_2 w_s}{1 - \rho_1 - 2\rho_2}\right)r_s\right] \tag{15}$$

Compute link efficiency We use hardware-powered parameters to determine LQ given through the network’s physical layer that is IEEE 802.15.4 standards to get link computation or efficacy. Low-rate wireless personal area networks (LR-WPANs) have their physical and medium access control (MAC) layers defined by IEEE 802.15.4, a technical standard. It offers a stable and adaptable standard for low-power, short-range wireless communication, which allows it for a broad range of IoT and other WSNs applications. Applications like industrial automation, home automation, sensor networks, and healthcare all make extensive use of the standard. The following factors are taken into account for LQ estimation: RSSI, SNR, along with LQI.

- RSSI (received signal strength indicator)

When estimating a transmitter's distance from a receiver based on signal power, RSSI seems a frequently utilized range-based parameter [34], whiuch can be calculated by using the following formula:

$$\mathrm{RSSI}_{\mathrm{dbm}} = 10\log_{10}\left(\mathrm{Power}_{\mathrm{recievedpacket}} + \mathrm{Background}_{\mathrm{noise}}\right) \tag{16}$$

The mean of RSSI

$$\overline{RSSI}\mathrm{w} = \frac{\sum_{i=1}^{N} rssi\mathrm{i}}{N} \tag{17}$$

whereby N denotes the entire number of computed $\mathrm{rssi}_{\mathrm{i}}$ in session w plus $\overline{RSSI}\mathrm{w}$ equals the RSSI mean.

- SNR (signal-to-noise ratio)

The SNR measures how loud the background noise is in relation to the received signal strength. Equation (18) can be used to represent it in another way, as the ratio of the strength of an undesired signal (surrounding noise) to the strength of a good signal (relevant data).

$$SNR\mathrm{dB} = 10\log 10\ (P\mathrm{Signal}/P\mathrm{Noise}) \tag{18}$$

In line with Eq. (19), which outlines SNR as calculating the RSSI of the obtained signal initially and noise around it second,

$$\mathrm{SNR}_{\mathrm{dBm}} = \mathrm{RSSI}_{\mathrm{dBm}} - \mathrm{BackgroundNoise}_{\mathrm{dBm}} \tag{19}$$

The mean of SNR

$$\overline{SNR}\mathrm{w} = \frac{\sum_{i=1}^{N} snr\mathrm{i}}{N} \tag{20}$$

in which $\overline{SNR}\mathrm{w}$ is the average signal-to-noise ratio, $\mathrm{snr}_{\mathrm{i}}$ is the SNR of each pkt that is precisely received, and N represents the entire number of SNRs that are computed within frame w.

- LQI (link quality indicator)

The LQI indicates the obtained signal's quality, which can be determined by SNR, or energy identification, and a mix of the two. By using the LQI score, one can estimate the quality of the link in a standard IEEE 802.15.4. The formula for it may be defined in this way:

$$\mathrm{LQI} = (\mathrm{CORR} - \mathrm{a})\mathrm{xb} \tag{21}$$

here a and b tend to be constant whose values vary according to the hardware connections, whereas CORR represents the hardware correlations.

The mean of LQI:

$$\overline{LQI}\text{w} = \frac{\sum_{k=0}^{n} lqi\text{k}}{n} \tag{22}$$

wherein n be the total number of pkts that arrived successfully as well $\overline{LQI}$w is the average of lqi_k in the time window (t_0, t_1).

As actually hardware LQEs have a lower cost than driven by software LQEs, they become common parameters for assessing link quality. The variance mean of the RSSI, SNR, along with LQI is utilized in order to estimate the LQ; this is referred to as the "hardware-based triangle metrics." The sum of the mean value of the LQEs then serves as CF's input variable [35].

The variance of LQEs (lq_{Δ}),

$$l_{q\Delta} = \sqrt{\left(\overline{SNR_w}\right)^2 + \left(\overline{RSSI_w}\right)^2 + \left(\overline{LQI_w}\right)^2} \tag{23}$$

CF (cost function) computation The combined value of LQEs, TE, along with the distance of the node from or to the SN is called CF [32], and it is calculated by

$$CF = \frac{(RE) \times \alpha + \left(\text{lq}_{\Delta}\right) \times \beta}{d\text{tance}} \tag{24}$$

Or,

$$CF = \frac{(TE) \times \alpha + \left(\text{lq}_{\Delta}\right) \times \beta}{d\text{tance}} \tag{25}$$

The above equations show how the CF is calculated for the initial period using just RE while further rounds using TE. The weighted coefficients α and β are utilized for modifying the energy or LQ values.

- The CN's selection

Recurrent and non-cooperative gaming theory serves as the foundation for the choice of CN [36, 37]. It is possible to pinpoint the strategic connections between N number of sensor nodes when they decide how to allocate assets, including energy consumption, data routes, along with task allocation, using non-cooperative game theory. Recurring game theory is useful for simulating time-recurring interactions between nodes. This makes it possible to create algorithms that facilitate communication, which are trustworthy or reliable data transmission, improving the accuracy and security of the data that the network stores. It also facilitates the creation of adaptive solutions to increase network lifetime through trustworthy energy management by providing an understanding of how node's activities fluctuate over time. Long-term security measures, including adaptive surveillance systems that learn from previous attacks and modify its defenses appropriately, can be analyzed with the help of this. In general, the overall network performance/ QoSs can be improved by these methods.

The CN with CH improves the lifetime or efficient use of energy of networks even more. The attempt to become CN is only initiated by CMs from CH which is expressed using the equations below:

$$G = \{N, S, U\} \tag{26}$$

at which S stands for the equivalent strategic area, U for the utility or the value that is assigned to the players, as well N for the players themselves. One way to express a group of strategies is with Eq. (27)

$$S = \{CN, CM\} \tag{27}$$

Every node attentively considers its options, strives to consume the least amount of energy, or maximizes its reward. Below Eq. (28) specifies the utility function.

$$U(S_i) = \begin{cases} 0 when S_i = CM, \forall i \in N \\ \frac{1}{C_{cm}} when S_i = CM \\ \frac{1}{C_{cn}} when S_i = CN \end{cases} \tag{28}$$

in which the expenditures to become CM or CN are denoted by C_{cm} and C_{cn}. Table 4 illustrates the outcomes of two individuals who became part of the game.

Assume that one participant chooses strategy CN, then the other participant will undoubtedly choose strategy CM according to their settlement. The combined approach of CN and CM delivers a greater reward for the 2nd opponent according to their corresponding outcomes.

$$\frac{1}{C\text{cm}} > \frac{1}{C\text{cn}} \tag{29}$$

Or,

$$\frac{1}{C\text{cn}} > 0 \tag{30}$$

But even if the choices are rearranged, both the players are able to pick combinations (CN, CM) or (CM, CN). As indicated by the next equation, the choice's outcome:

$$\frac{1}{C_{cn}}, \frac{1}{C_{cm}} \text{and} \frac{1}{C_{cm}}, \frac{1}{C_{cn}} \tag{31}$$

similar to Nash's equilibrium, there will be two players: CM and CN.

Results and discussion

The resultant analysis of the proposed ISERP is carried out in MATLAB, along with comparisons against conventional techniques done with respect to residual energy, longevity, and throughput of the network, active nodes, as well as network stability

Table 4 Game of strategy among CN and CM with two players

	CN	CM
CN	$1/C_{cn}$, $1/C_{cn}$	$1/C_{cn}$, $1/C_{cm}$
CM	$1/C_{cm}$, $1/C_{cn}$	0,0

and transmission delays. These techniques include FUCARH, ABC-SD, ETLHCM, and EAMR. The primary objective of the proposed method is to significantly improve the network's lifetime through minimizing frequent CH function transition and additional costs with reliable communication. In comparison to other corresponding methodologies, simulation findings indicated improved results. In Table 5, you can see the simulations that were run throughout the implementations.

Network lifetime

Usually represents the number of rounds depending on how long the network can function. It describes how many rounds must pass before the nodes in the region have finished their tasks and will expire. Because of an integrated energy harvesting mechanism in the current ISERP plus decreasing in CH transitions as far as possible, the lifespan of the network is significantly enhanced when compared with additional equivalent protocols, as illustrated in Table 6. Also, there are significantly less control Pkts, and this extends the lifetime of the network.

Network stability metrics reveal future network estimations. This correlates directly with the longevity of the network. Figure 3 and Table 6 show the network stability of the proposed ISERP, showing that the first node of the proposed technique died at round 880, a huge extent over equivalent methods. Similar to how practically all nodes in the comparable protocols fail at round 1700, ISERP succeeded in delivering those packets at round 1900. It demonstrates that the suggested scheme outperforms other present protocols in terms of lifetime. Because of the energy units that each node harvests, a little amount of CH shuffles, and relatively low control pkt overhead, ISERP has a highly stable network.

Table 5 Simulation parameters with values

Parameters	Values
Network coverage area	(0, 0)–(200, 200) m
Number of sensor nodes	200
Central station location	At the center location of the coverage area
Initial energy $E_{Initial}$	1.5 J
E_{elec}	50 nJ/bit
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
Data packet size	500 bytes
Broadcast packet size	25 bytes

Table 6 Lifespan of nodes against rounds

Protocols	FUCARH	ABC-SD	ETLHCM	EAMR	Proposed
Steady-state (first node died)	500	300	210	790	880
Network lifetime (60% of nodes died)	1100	1000	450	1170	1300
Network lifetime (90% of nodes died)	1150	1150	500	1700	1900

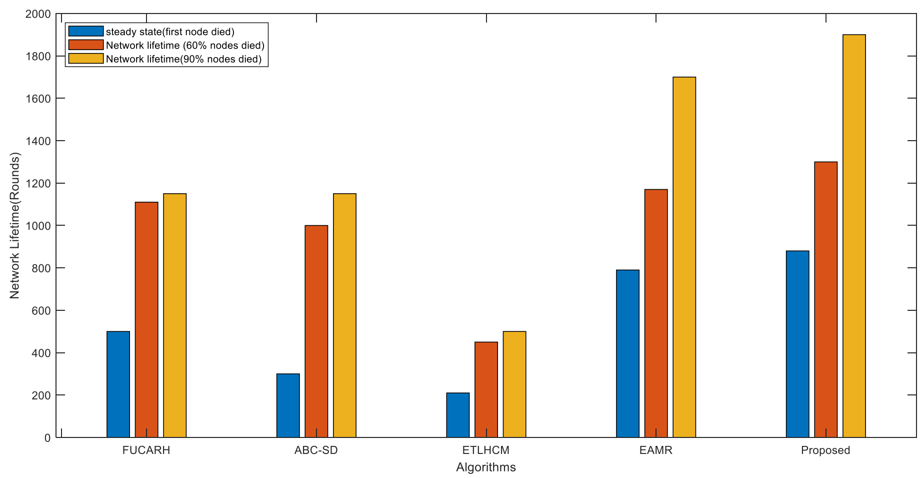

Fig. 3 Analysis about network lifespan

Energy efficiency

Leftover battery power or network energy at the beginning of all rounds can be referred to as residual energy. An examination of which proposed ISERP's remaining energy is shown in Fig. 4, which demonstrates that it has greater stability instead of the residual power of opposing algorithms shown in Table 7.

According to analyzed statistics, other equivalent methods' remaining power was completely depleted within 7000 rounds; however, our ISERP's leftover energy continued to work after that. Additionally, there continued to be approximately 27 J more energy.

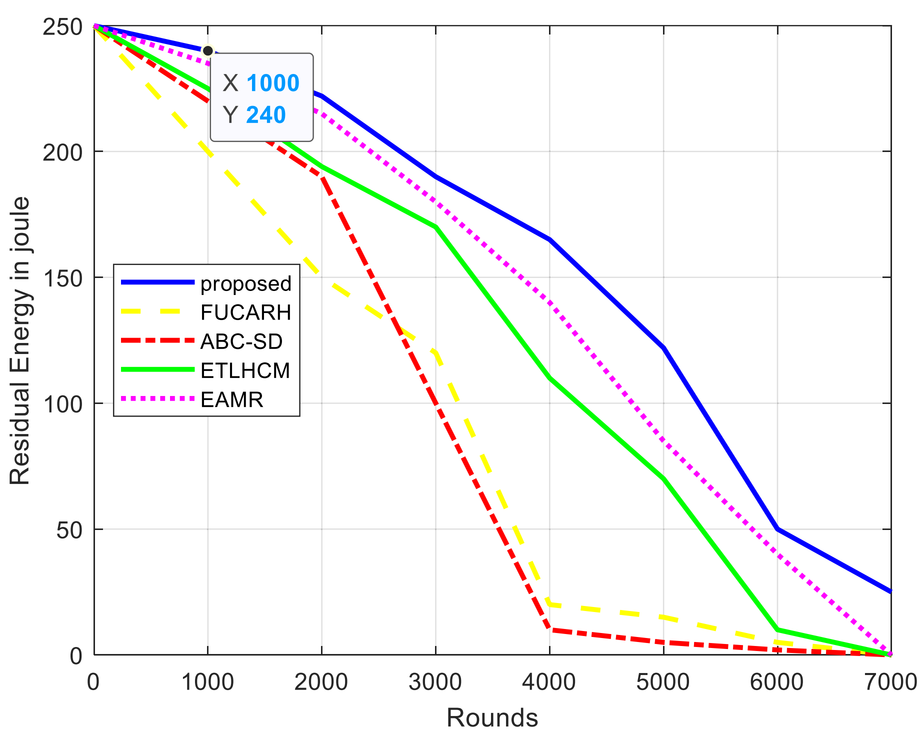

Fig. 4 Residual energy analysis

Table 7 Rounds versus energy leftover

Rounds	Protocols				
	FUCARH	**ABC-SD**	**ETLHCM**	**EAMR**	**Proposed**
0	250	250	250	250	250
1000	200	220	225	234	240
2000	150	192	196	215	222
3000	125	100	172	180	190
4000	20	10	110	141	165
5000	15	5	70	85	122
6000	5	2	10	40	50
7000	0	0	0	0	27

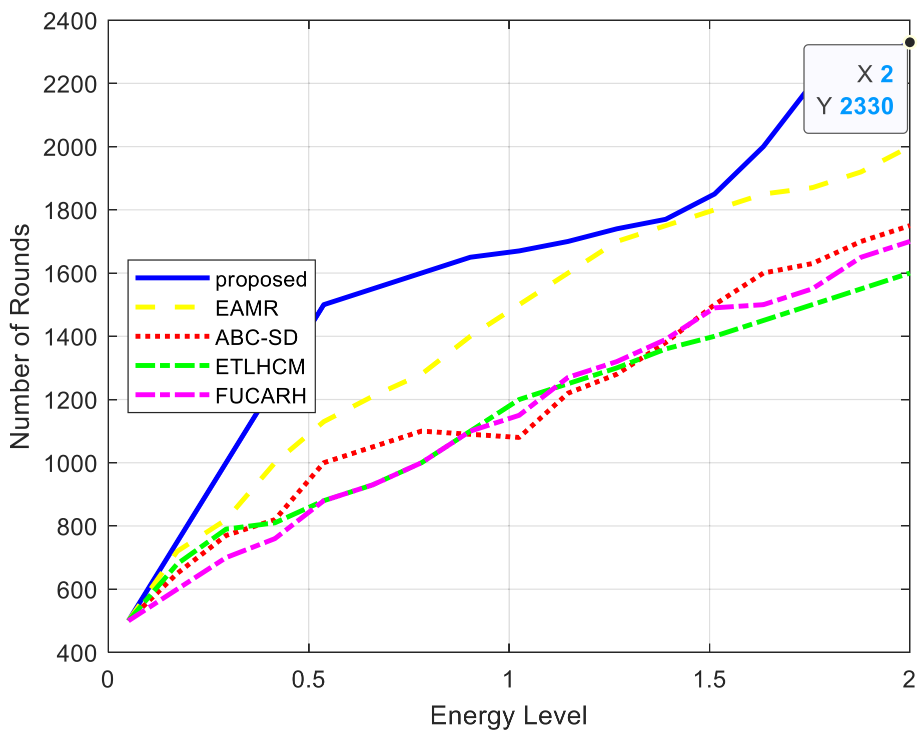

Fig. 5 An examination of average energy usage

Figure 5 displays how much energy is drawn from every single node during a certain round, which corresponds to an average cost of energy. Comparing ISERP against additional equivalent protocols, it achieves significantly improved outcomes while consuming less energy, as shown in Table 8. Because all sensors contain an added harvesting of energy unit, there is less CH moving about, and there is minimal cost; therefore, ISERP beats comparable algorithms in the current contest.

Long-term network maintenance is the primary goal that drives the proposed ISERP. The fundamental source of this is due to the integration with the wireless energy harvesting unit into the proposed framework, and this increases the lifetime

Table 8 Approximate energy usage vs rounds

Energy level	Protocols				
	FUCARH	**ABC-SD**	**ETLHCM**	**EAMR**	**Proposed**
0.05	500	500	500	500	500
0.5375	880	1000	880	1130	1500
1.025	1150	1080	1200	1500	1670
1.5125	1490	1490	1400	1800	1850
2.0	1700	1750	1600	2000	2330

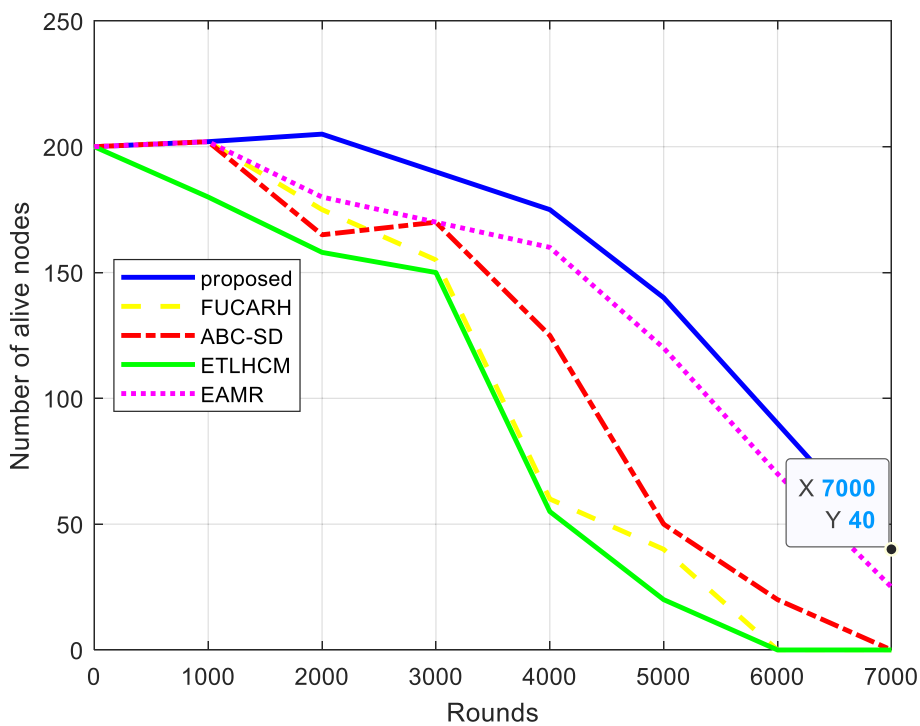

Fig. 6 An examination of total alive nodes

of every wireless sensor node in the network. According to Fig. 6, nodes get started dropping off around 3000 rounds, and it turns extremely complex about 6000 rounds.

Table 9 shows that, apart from EAMR, which has 25% of its nodes still functioning, as well-proposed ISERP, which has 40% of its nodes surviving to the conclusion of the phase, the entire nodes used by comparable algorithms perish by 7000 rounds or the final phase.

Delay analysis

Typically refers to the amount of time needed for the data packet to be transmitted between a source to its receiving node in the network. Due to the choice of CH, a CG, along with additional functions like the choice of CN, the proposed method's starting findings are generally similar to those of its equivalents. The amount of delay is significantly decreased once the choice is picked up, as seen in Table 10.

Table 9 Active nodes over rounds

Rounds	Protocols				
	FUCARH	**ABC-SD**	**ETLHCM**	**EAMR**	**Proposed**
0	200	200	200	200	200
1000	202	202	180	202	202
2000	175	165	158	180	205
3000	155	170	150	170	190
4000	60	10	125	160	175
5000	40	50	20	120	140
6000	0	20	0	70	90
7000	0	0	0	25	40

Table 10 Delay from beginning to end vs. time (s)

Rounds	Protocols				
	FUCARH	**ABC-SD**	**ETLHCM**	**EAMR**	**Proposed**
0	500	500	500	500	500
2000	490	500	500	450	480
4000	450	490	470	410	420
6000	410	440	400	380	350
8000	400	400	350	330	300
10000	360	360	320	310	250
12000	315	320	300	295	200
14000	300	290	280	260	180
16000	299	282	270	211	120

WEH units within CH as well CG serve as one of the aspects that helps to keep the overall delay to a minimum. That additional energy allows them to keep performing constantly and with maximum travel speed in the direction of SN over an extended period of time Figure 7.

Throughput

It is the timely and reliable transmission of data between node sensors to their respective SN. This method is less costly when there is an increased throughput. The prospective strategy employs CG which functions like a layer of communication from CH to SN in order to provide maximum throughput. It decreases the possibility of loss of data packets that could happen in immediate interaction when there is an extended range.

Throughput, i.e., bits/s is depicted in Fig. 8 and is provided in Table 11 to illustrate that the proposed ISERP performed better than the rest of the algorithms until the end of the phase. At the beginning of the process, almost every algorithm operates with a similar throughput.

In analyzing throughput, a pair of metrics was included. Equation (32) will be implemented to determine the rate at which packets were lost as well the number

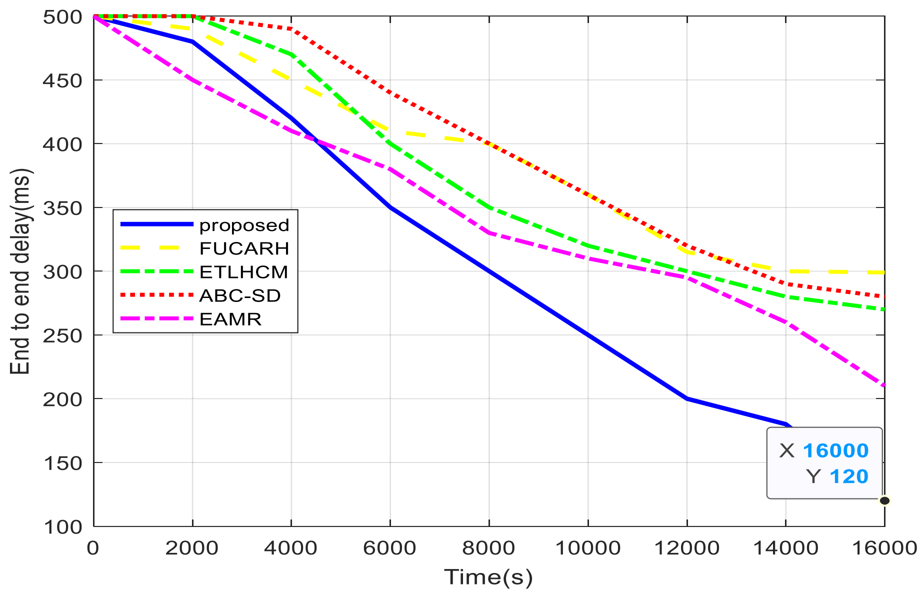

Fig. 7 Delay analysis

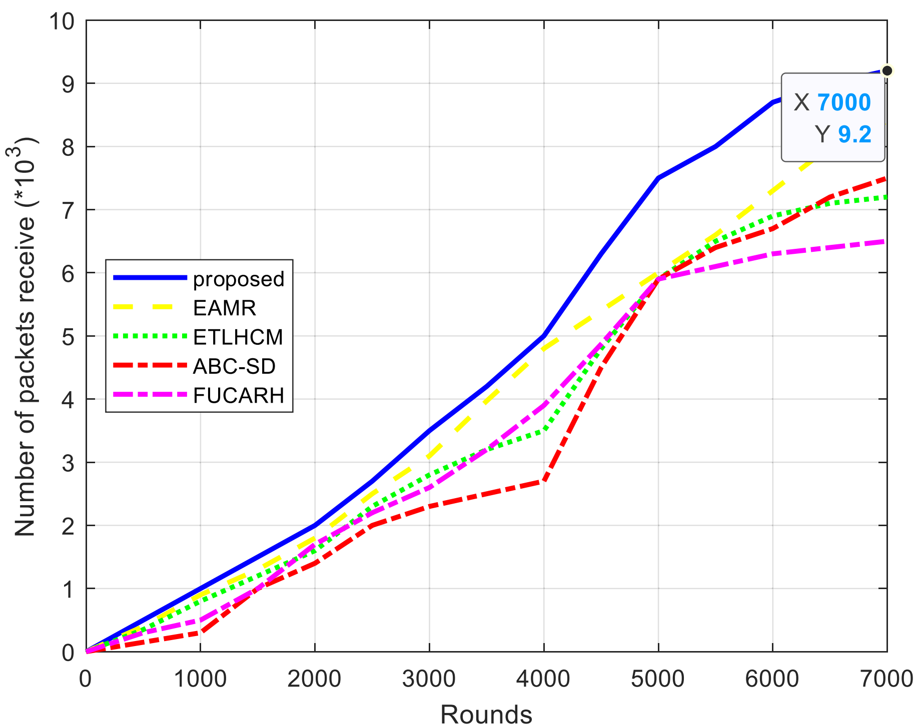

Fig. 8 Throughput evaluation

of transmitted packets that the SN receives during the completion of the period of simulation.

$$PL = 1 - \frac{\sum \text{ReceivedPktsbysinknode}}{\sum SentPktstosinknode} \tag{32}$$

in which PL stands for packet loss.

Table 11 Ratio of throughput to rounds

Rounds	Protocols				
	FUCARH	ABC-SD	ETLHCM	EAMR	Proposed
0	0	0	0	0	0
1000	0.5	0.3	0.8	0.9	1
2000	1.7	1.4	1.6	1.8	2
3000	2.6	2.3	2.8	3.1	3.4
4000	3.9	2.7	3.5	4.8	5
5000	5.9	5.9	5.9	6	7.5
6000	6.3	6.7	6.9	7.3	8.7
7000	6.5	7.5	7.2	8.4	9.2

Conclusion

The present research proposes and develops an ISERP-modified routing protocol, a significant approach for IoT in WSNs. IoT-based WSNs have a variety of issues and because of such challenges, we have focused on improving network performance, higher the percentage of active nodes, minimizing delay also transmission loss, consuming less energy, as well as enhancing detecting suspicious nodes in it. The proposed approach incorporates a WEH unit into each sensor to optimize the network longevity with respect to energy cost, also it has an integrated protective feature (CN) that detects undesirable node operation or adds that node to block. According to how much of CF, it gives the CH or CG jobs. Each node's CF was calculated using the primary parameters of its distance to or from SN, the combined value of LQEs, along with RE or TE. Alongside having usually well-functioning nodes, this approach also provides a tolerant of failures feature that enables a small number of failing nodes to carry out data transfer activities while maintaining the network's functionality. In relation to the network's longevity, operational efficiency, cost of energy, delays as well stability or security, our proposed protocol scored very well while beating the remaining comparable existing routing protocols, i.e., with the proposed ISERP, CHs use 33% less energy in comparison to existing techniques, and 40% of all nodes remain active until the end of the phase. Utilizing this approach, our research directions are as follows; deploying the parameter that affects functionality of RF to DC transformation within the network that provides accurate or real-world results along with determining the ideal variables for an energy-effective wireless powered sensor network for analyzing the energy consumption of power beacons. Additionally, we will implement an energy-efficient routing technique with realistic IoT objects in a real-world environment which will be appropriate for three-dimensional contexts in our future work.

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Authors' contributions
Each author has contributed to the framework of this research work as well as analyzed that all data, including figures, tables, and codes have developed in an original or transparent manner.

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Availability of data and materials
The data used to support the findings of this research are available upon request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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