

An Energy-Efficient Cooperative Routing Protocol for Wireless Sensor Networks (WSNs) based IoT applications: A Review

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Abstract: The Internet of Things (IoT) has grown rapidly and wireless sensor networks (WSNs) have played a key role in the collection and transmission of data from most environments. However, the energy consumption of WSNs nodes, particularly, seriously degrades the scalability and longevity of IoT systems. In order to solve this problem, an innovative routing mechanism that provides a balance between effective data delivery and energy conservation are required. Cooperative communication, a cross-layer method employing the collective resource of multiple nodes, seems to be an effective way of improving energy efficiency for WSN-based IoT. This literature review investigates the performance of various methods and identifies research needs while reviewing the existing research in energy-efficient cooperative routing protocols in WSN with IoT integration.

Keywords: WSNs; IoT; Energy; Routing; Cooperative.

Introduction

A collection of wireless sensor nodes that synchronize their activities to pass information to and from the base station is a wireless sensor network (WSN). Each node is powered by a limited-energy battery [1]. Besides, the sensing as well as transmitting range of nodes is restricted and their processing power is insufficient. The duration that the node runs depends on how much energy has been stored within its battery. The energy stored is utilized for sensing, processing, and communication, among other node functions. The tiny batteries in sensor nodes are usually not rechargeable or replaceable. Although energy harvesting can be done in a variety of ways, energy management is still necessary. Thus, employing energy-efficient protocols for WSNs to manage the restricted battery capacity is the most challenging [2].

WSNs are essential to IoT. IoT-based WSNs' sensors continuously scan their environment and instantly notify the base station (BS) of any events they find. An IoT-based WSN also has a gateway for uploading the collected data to the IoT Cloud. The BS may act as the gateway in certain systems. Users can access the data they have uploaded to IoT Cloud remotely at any time. Water quality monitoring [3], air quality monitoring [4–6], smart agriculture [7, 8], health and environments [9,10], smart irrigation [11], smart cities and smart buildings [12–15], smart wearables [16,17], and more are some of the uses of IoT-based WSNs applications.

Figure 1 illustrates the two different categories of communication protocols that we distinguish in this article: One instance of noncooperative communication is the transmission of a direct link from a source node S to the CH. It is known as direct transmission and is indicated by the letter d. Cooperative communications, is the process by which a source node S can transmit data to the CH with the help of a relay node R.

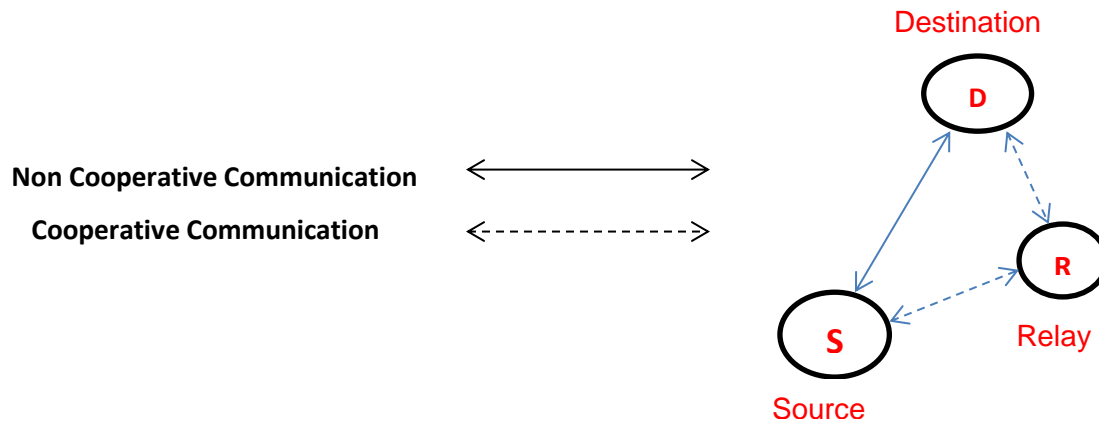


Figure:1 Cooperative and Non cooperative communication

Cooperative routing is fundamentally different from conventional, non-cooperative routing techniques by taking advantage of cooperative communication smart route selection at the network layer [18]. Rather than using a single node to forward data directly to the destination, cooperative routing uses several nodes working together to forward the data [20]. This cooperative method can alleviate channel fading effects, enhance reliability, and dramatically decrease energy usage [21]. The decrease in energy usage is due to the capability to spread the transmission load across several nodes, enabling shorter transmission ranges and reduced power levels [22]. In addition, cooperative diversity methods can improve signal-to-noise ratio, thus resulting in enhanced data delivery rates and minimized retransmissions [19]. Yet, cooperative communication introduction requires effective node selection, relay path optimization, and synchronization in order to prevent additional overhead and possible performance loss [23].

Energy efficiency presents some unique issues when WSNs are integrated into the Internet of Things [24], [25]. An IoT system's power consumption increases with the number of devices, and sensor node devices' limited resources further shorten the network's lifespan [26].

Robust real-time forwarding necessitates additional complexity since energy-efficient protocols demand punctual delivery of critical information [27]. In addition, the diversity of IoT devices as well as the unpredictability of data traffic patterns complicate it further to create an energy-efficient routing system that can be rolled out worldwide [28]. Security issues complicate it further since energy-consuming encryption and authentication processes might offset gains from energy-efficient routing [3].

Related work

A number of cooperative routing strategies to optimize data transfer and energy expenditure have been described in the literature [18, 22, 29, 30]. In some protocols utilizing cluster-based techniques for organizing nodes into clusters, the cluster leaders are chosen to direct data aggregation and transfer [31]. Such a hierarchical scheme reduces the number of overall transfers and regulates nodes' energy expenditures [32]. Other protocols employ sleep/wake-up methods to further reduce energy usage by switching off idle nodes [32], [33].

This minimizes waste energy of idling listening and maximizes network lifetime [26]. Additionally, several optimization approaches, including genetic algorithms [18], particle swarm optimization [34], and ant colony optimization [35], have been applied for enhancing the node selection effectiveness as well as route planning in cooperative routing protocols [36].

Saima Jamil et al. [5] presented a Cooperative Power and Energy-efficient routing protocol (COPE). COPE utilizes cooperative communication to enhance the energy efficiency, packet delivery ratio, and throughput of WSNs. The authors compared the effectiveness of COPE with PEGASIS and LEACH, both non-cooperative protocols. In each metric that was proposed, COPE outperformed these non-cooperative methods, based on simulation results. The research didn't consider, though, the protocol's node failure and security attack resilience and the details of COPE's cooperative communication method.

Unlike COPE, Anshika Sharma et al. proposed MHSEER, a Meta-heuristic protocol where security is given more importance compared to energy conservation [3]. The two-phase MHSEER method adopts a heuristic algorithm for secure data routing in phase one and Counter-Encryption Mode (CEM) for data encryption in phase two. MHSEER demonstrated an impressive throughput improvement and a reduction in packet drop ratio, latency, energy usage, and defective paths when compared to Sectrust-RPL, HBEER, SEHR, and SEAMHR. Although CEM improves security, its computational cost may have an effect on energy efficiency, especially in environments with limited resources.

Sampoorna Bhimshetty et al. introduced a reinforcement learning (RL)-based energy-efficient routing protocol [37]. Their method considers the energy profiles of the nodes and employ a Deep Q-Network (DQN) to determine the best transmission channel. A reward function that considers data transfer efficiency and energy outflow is employed for training. The model performed better than LEACH and Fuzzy C-Means (FCM) in active node number, energy saving, network longevity, and data transmission efficiency. However, the accuracy of the energy model and the reward function design may be crucial to the protocol's effectiveness, and the DQN's training may involve a lot of work.

Moizuddin Mohammed et al [24]. Presented, Deep Convolutional Neural Network and Metaheuristic Algorithms. a cluster head selection protocol for WSN-IoT that is tuned for energy efficiency. In order to choose the best cluster heads (CHs), the protocol makes use of a tree hierarchical Deep Convolutional Neural Network (DCNN), taking into account variables such as cluster density, traffic rate, energy, collision, latency, throughput, and distance from the capacity node. Additionally, to achieve best-path selection, the hybrid optimization method of the Marine Predators Algorithm (MPA) and Woodpecker Mating Algorithm (WMA) maximizes trust, connectivity, and Quality of Service (QoS) parameters. In comparison to other options, the simulation results showed a much reduced delay, a greater delivery ratio, and a smaller packet loss. Implementation in low-resource systems is hampered by the DCNN and hybrid optimization algorithm's simplicity.

R Patil et al. proposed the work Energy Efficient Cooperative Communication Protocol for Heterogeneous EECPH [9], which targets heterogeneous WSNs by introducing different levels of energy nodes; EEDC [38], which uses a region-based hierarchical clustering routing framework; and Co-EEORS [6], which is specifically made for underwater WSNs, focus on specific aspects of cooperative communication and energy efficiency. These protocols demonstrate the variety of energy-efficient cooperative routing methods available, but they also highlight the need for tailored solutions for specific WSN characteristics and application requirements.

Comparative Analysis

The variations in simulation environments, evaluation criteria, and network topologies employed in the various researches make it challenging to directly compare the various protocols. However, a few broad conclusions can be drawn. Clustering-based protocols typically use less energy than non-cooperative ones [20], [18]. Performance is further enhanced by the application of optimization algorithms, albeit this comes at the cost of increased computing complexity [36], [34]. Although protocols based on machine learning and deep learning show promise in maximizing routing choices and adjusting to shifting network conditions [37], [24], their efficacy is heavily dependent on the complexity of the model and the quality of the training data. Energy efficiency and security must be traded off because integrating security mechanisms is necessary but often expensive [3], [39].

Table1: Comparison of Various Routing Protocols

Protocols	Formation of cluster	Allocation of slot	Method of Communication	Consumption of Energy	Usage
LEACH	Yes	Self-allotment	One hop	Medium	General
MHSEER	yes	Self- allotment	One hop	Low	General
RLEERP	Yes	Self- allotment	One hop	Low	General
DCNMA	Yes	Self- allotment	One hop	Low	General
ES-MAC	Yes	Allotment by CH	One hop	Medium	General
EE-MAC	Yes	Allotment by CH	One hop	Medium	General
LEC-MAC	Yes	Allocation by CH	One hop	Medium	General
COPE	Yes	Self-allotment	Multi Hop	Medium	General
ECCPH	Yes	Self-allotment	Multi Hop	Medium	General

Research Gaps and Future Directions

Even with significant advancements, there are still a number of unanswered questions in the area of energy-efficient cooperative routing for WSN-based IoT:

Cross-layer optimization: Most existing protocols operate on a single network stack tier. Future research should look into cross-layer optimization techniques to distribute resources across layers in a way that maximizes performance and energy efficiency [4].

Dynamic network conditions: The majority of protocols assume static network topologies. To handle dynamic network situations, such as node movement, failure, and changing environmental elements, robust protocols are needed [40].

Heterogeneity: As IoT devices become more diverse, protocols that can handle varying node capabilities and communications protocols must be developed [25].

Energy efficiency and security trade-offs: Security and energy efficiency are subject to trade-offs. Environments with limited resources require light security measures that minimize energy overhead [41].

Real-time applications: Low-latency, energy-efficient protocols with good dependability are needed for real-time applications [4].

Performance analysis and mathematical modelling: To accurately predict how well different protocols will perform in different network environments, strict mathematical models are

needed. To facilitate fair comparisons, standardized performance analysis metrics should be developed [24].

Conclusions

To fully utilize WSN-based IoT, energy-efficient cooperative routing techniques are essential. Although there has been a lot of development in this area, there are still a lot of problems to be solved. Filling in the identified research gaps and creating scalable, reliable, and energy-efficient solutions that can support a range of IoT applications in harsh and varied settings should be the main goals of future research. To do this, a multidisciplinary strategy that combines knowledge of machine learning, security, optimization algorithms, and communication networks is crucial. The various methods, together with their advantages and disadvantages, have been outlined in this review, which has also laid the groundwork for further advancement and study in this crucial area. The findings underscore the need for a comprehensive approach that considers not only energy economy but also dependability, security, and adaptability to evolving network conditions. In order to construct really durable and effective WSN-based IoT networks, future research must focus on developing protocols that can naturally integrate the competing needs.

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