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A novel strategic trajectory-based protocol for enhancing efficiency in wireless sensor networks

Rangaraj Gopalakrishnan[1]✉, Angamuthu Senthil Kumar[2]

[1] Periyar University, Salem, 636011, India
[2] Thiruvalluvar Government Arts College, Rasipuram, 637401, India

[1] gopaldharun1978@gmail.com✉, https://orcid.org/0000-0003-2456-265X
[2] senthilkumarmca76@gmail.com, https://orcid.org/0000-0001-5131-7428

Abstract

This research presents a comprehensive approach to enhance the efficiency and performance of Wireless Sensor Networks (WSNs) by addressing critical challenges, such as race conditions, reservation problems, and redundant data. A novel protocol combining Self-Adaptive Redundancy Elimination Clustering and Distributed Load Bandwidth Management is proposed to mitigate these challenges. The work intelligently extracts transmission hops and any-cast transmission features from diversity traffic information obtained through trace files, to eliminate nodes harboring redundant data. To optimize network organization, the number of clusters is dynamically adjusted according to the node density using the affinity propagation technique. Furthermore, load balancing is achieved by reallocating available bandwidth through bandwidth re-segmentation. The research also delves into the Proposed Network Infrastructure and Channel Coordination. The architecture encompasses cooperative clustering of nodes, strategic access point selection, data compression, and channel migration. By fostering collaboration among nodes within clusters, selecting access points judiciously, and employing efficient data compression techniques, the network overall efficiency is significantly improved. Channel migration strategies further bolster the network agility and responsiveness. The integration of Channel Sensing enriches the approach by collecting channel state information, enriched with spatial and temporal node information. This added insight empowers the network to make more informed decisions regarding channel allocation and coordination contributing to reduced interference and optimized data transmission. As a result of the work, the proposed methodology achieves remarkable results, including an average Packet Delivery Ratio of 99.1 % and an average reduction of packet loss by 4.3 % compared to existing studies. Additionally, the proposed protocol exhibits an average throughput improvement of 4.7 % and reduces average network delay to 52 milliseconds highlighting its significant contributions to the enhancement of WSN performance.

Keywords

wireless sensor networks, redundancy elimination clustering, security

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УДК 004.72

Новый стратегический траекторно-базированный протокол для повышения эффективности беспроводных сенсорных сетей

Рангарадж Гопалакришнан[1]✉, Ангамуту Сентил Кумар[2]

[1] Университет Перияр, Салем, 636011, Индия
[2] Государственный колледж искусств Тируваллувара, Расипурам, 637401, Индия

[1] gopaldharun1978@gmail.com✉, https://orcid.org/0000-0003-2456-265X
[2] senthilkumarmca76@gmail.com, https://orcid.org/0000-0001-5131-7428

Аннотация

Исследован комплексный подход к повышению эффективности и производительности беспроводных сенсорных сетей путем решения критических проблем, таких как условия гонки, проблемы резервирования и избыточные

данные. Для решения этих проблем предложен новый протокол, сочетающий в себе самоадаптирующуюся кластеризацию с устранением избыточности и управление полосой пропускания распределенной нагрузки. Используется разумный способ для извлечения функции передачи сообщений с «перескоком» через узлы (их пропуском) и передачи сообщений любому из ближайших узлов. Для этого используется информация о разнесенном трафике, получаемая на основе файлов трассировки, исключая узлы с избыточными данными. Количество кластеров динамически регулируется в зависимости от плотности узлов, используя метод распространения сходства. Балансировка нагрузки достигается посредством перераспределения доступной полосы пропускания и повторной сегментации полосы пропускания. В исследовании представлена предлагаемая сетевая инфраструктура и координация каналов. Архитектура включает в себя совместную кластеризацию узлов, выбор точки доступа, сжатие данных и миграцию каналов. Эффективность сети значительно повышается за счет взаимодействия между узлами внутри кластеров, разумного выбора точек доступа и использования эффективных методов сжатия данных. Стратегия миграции каналов еще больше повышает гибкость и оперативность сети. Интеграция способности обнаружения канала обогащает подход за счет сбора информации о состоянии канала и дополнения пространственной и временной информации об узлах. Эта дополнительная информация позволяет сети принимать более обоснованные решения относительно распределения и координации каналов, способствуя снижению помех и оптимизации передачи данных. Предложенная методология позволила получить средний коэффициент доставки пакетов (PDR) равный 99,1 % и среднее снижение потерь пакетов на 4,3 % по сравнению с существующими исследованиями. Новый протокол продемонстрировал повышение средней пропускной способности на 4,7 % и снижение средней задержки сети до 52 мс, что подчеркивает его значительный вклад в увеличение производительности WSN.

Ключевые слова
беспроводные сенсорные сети, кластеризация с устранением избыточности, безопасность

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Introduction

Wireless Sensor Networks (WSNs) have emerged as a vital technology for monitoring and collecting data from diverse environments. However, the effective operation of WSNs faces significant challenges, including race conditions, reservation problems, and redundant data storage. These challenges can lead to unpredictable network behavior, inefficient resource utilization, and increased communication overhead [1–4]. To overcome these challenges, this research introduces a novel approach that combines Self-Adaptive Redundancy Elimination Clustering and Distributed Load Bandwidth Management. The objective is to enhance the overall efficiency, reliability, and scalability of WSNs, ultimately improving their utility in various applications, such as environmental monitoring, healthcare, and industrial automation. The primary focus of this research is to devise a solution that dynamically adapts to changing network conditions and optimizes resource utilization. By extracting transmission hops and any-cast transmission features from diversity traffic information sourced from trace files, the proposed approach aims to identify and eliminate nodes that carry redundant data. This reduction in redundant information not only conserves network resources but also reduces data transmission latency. A critical aspect of the proposed solution is its ability to automatically adjust the number of clusters based on the node density. Leveraging the affinity propagation technique, the network self-organizes into clusters, aligning with the density of nodes in specific regions. Additionally, the research tackles the challenge of load balancing by redistributing available bandwidth through a process called bandwidth re-segmentation. This adaptive approach ensures that no single node or cluster becomes a bottleneck enhancing the network responsiveness and resource utilization [5–9]. The architecture of WSN is shown in Fig. 1.

The research further explores the proposed network infrastructure, which encompasses cooperative clustering of nodes, strategic access point selection, data compression, and channel migration. These components collectively contribute to the robustness of the network architecture. By optimizing the way nodes collaborate within clusters, strategically placing access points, employing efficient data compression algorithms, and intelligently migrating channels, the network achieves improved data throughput and reduced congestion.

Furthermore, the inclusion of Channel Sensing enriches the network understanding of the wireless channel environment. By collecting channel state information along with spatial and temporal node characteristics, the network

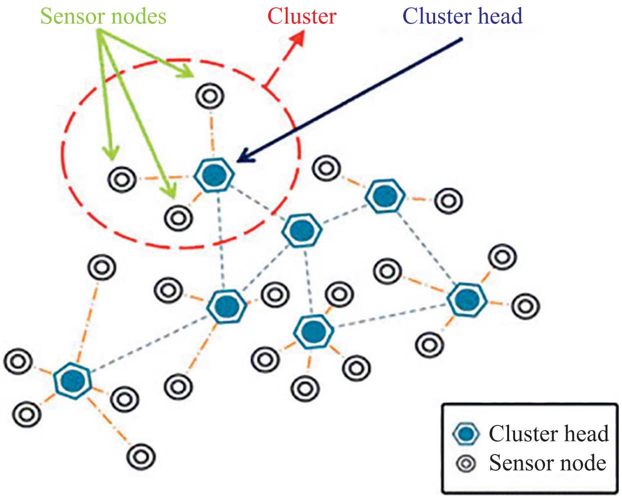

Fig. 1. Architecture of Cluster based WSN

gains valuable insights into the availability and quality of channels. This information is leveraged to make informed decisions about channel allocation and coordination, thereby minimizing interference and maximizing data transmission efficiency. In summary, this research proposes a holistic solution to address critical challenges in WSNs. By synergistically integrating self-adaptive redundancy elimination clustering, distributed load bandwidth management, and sophisticated channel sensing, the proposed approach aims to propel the capabilities of WSNs to new heights. The subsequent sections of this paper delve into the technical details of the proposed methodology, experimental setup, results, and comparisons with existing solutions, thereby validating the efficacy of the approach in improving the performance of WSNs in real-world scenarios. The subsequent sections of this paper delve into the technical intricacies of the proposed methodology, spanning route setup, route discovery, clustering of nodes, access point selection, and redundancy elimination strategies. We then delve into the Cooperative Clustering mechanism and the integration of channel sensing for enhanced trace file generation. Additionally, we present an innovative approach to Access Point Selection and discuss the intricacies of the Redundancy Elimination and Outage Interference Cancellation Model.

Related work

WSNs have gained significant attention due to their wide range of applications. Among the key challenges in the context of WSNs, identifying network layer attacks is a critical concern. The paper [10] delves into the problem of identifying network layer attacks in WSNs with the aim of developing intrusion detection systems. In their work, the authors outline 15 types of behavior, which include 14 states under attack and the normal state, providing a comprehensive framework for characterizing network behavior in WSNs. Additionally, they specify identification features crucial for the detection of network layer attacks. A notable contribution of the paper is the proposed technique for identifying attacks, which combines the Random Forest algorithm and a probability classifier. This innovative approach offers a promising avenue for accurately detecting and classifying network layer attacks in WSNs. Furthermore, the paper discusses a detailed study of the relationship between the accuracy of the probability classifier and the average number of features used. This analysis allows for the reduction of the feature space to a single feature optimizing the detection process. The paper highlights the relative constancy of the dependence values for most attacks in the range of 0 to 0.7 ± 0.15, followed by a decrease indicating the quality of identification. These findings offer valuable insights into the behavior and identification of network layer attacks in WSNs. Race conditions and reservation problems have been acknowledged as major hurdles in WSNs. Alleviating these challenges requires efficient synchronization and resource allocation mechanisms. Previous works in [10] proposed a distributed reservation protocol that mitigates contention and collision issues enhancing the predictability of network behavior. Similarly, [11] introduced a time-slot-based coordination scheme that effectively addresses race conditions ensuring synchronized access to shared resources. Redundancy elimination in WSNs has been a focus to optimize network performance. Research by [12] proposed a data fusion approach to identify and eliminate redundant data in multi-hop WSNs. Their method reduced communication overhead and conserved energy by aggregating similar data packets. In another study [13], a clustering-based technique is presented that removed duplicate data at the cluster head, enhancing overall data integrity and network efficiency. Load bandwidth management plays a vital role in maintaining balanced data traffic [14] devised a load-aware routing algorithm that dynamically adjusts routes based on network load preventing congestion and maximizing throughput. Additionally, [15] introduced a bandwidth reservation scheme that optimizes channel utilization in heavily loaded networks by preemptively allocating resources to critical tasks [16–18]. While prior research has provided valuable insights into addressing individual challenges, there is a gap in the literature concerning the comprehensive integration of redundancy elimination, load balancing, and adaptive clustering in WSNs. This research aims to bridge this gap by proposing a holistic approach that combines these techniques to enhance network performance [19–22]. In the following sections, we present a novel protocol that leverages the strengths of affinity propagation for self-adaptive clustering, dynamic bandwidth re-segmentation for load balancing, and channel sensing for improved channel allocation. This integrated approach builds upon the foundations laid by previous works and strives to overcome limitations inherent to individual solutions. The comparison of the existing works can be found in Table 1.

In response to the issues identified in the literature review, our proposed framework introduces innovative solutions aimed at elevating the efficiency and performance of WSNs. Despite the valuable contributions of previous studies across various WSN aspects, challenges associated with mitigating race conditions, reservation problems, and redundant data persisted. Our framework, which seamlessly integrates Self-Adaptive Redundancy Elimination Clustering and Distributed Load Bandwidth Management, takes a comprehensive approach to address these challenges. The unique amalgamation of these components exhibits intelligent extraction of transmission hops and any-cast transmission features from diverse traffic information, as validated through trace file analysis. This intelligent process effectively eliminates nodes harboring redundant data, marking a significant advancement in overcoming persistent challenges observed in earlier research.

Methodology

The methodology of this research encompasses several interconnected phases that collectively constitute the proposed protocol for Self-Adaptive Redundancy Elimination Clustering, Distributed Load Bandwidth Management, and Cooperative Clustering. Each phase aims to address specific challenges and contribute to the overall enhancement of WSNs.

Table 1. Comparison of current solutions

Reference	Method	Main Contributions	Focus Areas
[10]	Random Forest, Probability Classifier	– Identifies 15 types of network layer behaviors including 14 attack states and normal state. – Proposes a technique combining Random Forest and probability classifier for attack identification. – Analyzes the relationship between accuracy and feature count enabling feature reduction to optimize detection. – Reveals relative constancy of dependence values for most attacks within a certain range followed by a decrease corresponding to identification quality.	Network layer attack identification, Behavior analysis in WSNs
[11]	TTDD	Proposes a two-tier data dissemination approach in large-scale WSNs. Provides efficient and reliable data delivery in WSNs with improved scalability and reduced energy consumption	Data dissemination, scalability, energy efficiency
[12]	RE-based cluster-head selection	Introduces a cluster-head selection algorithm based on residual energy levels. Enhances network lifetime and efficiency for Internet of Things (IoT) applications	Cluster-head selection, IoT applications
[13]	QWRP	Presents QWRP, a query-driven virtual wheel-based routing protocol improving data transmission efficiency in WSNs with mobile sinks	Routing protocol, mobile sinks
[14]	LBRR	Proposes LBRR, a load-balanced ring routing protocol for heterogeneous sensor networks. Balances traffic and improves network performance	Routing in heterogeneous WSNs
[15]	Ring routing	Introduces an energy-efficient routing protocol for WSNs with mobile sinks. Enhances energy conservation and prolongs network lifetime	Routing with mobile sinks, energy efficiency
[16]	Vertical and horizontal segregation data protocol	Presents a data dissemination protocol based on vertical and horizontal segregation. Improves data delivery efficiency in WSNs	Data dissemination, efficiency
[17]	Hilbert-chain topology for energy conservation	Proposes the use of Hilbert-chain topology to conserve energy in large-scale WSNs. Enhances energy efficiency and network longevity	Topology for energy conservation
[18]	Optimal location for mobile sink in WSNs	Investigates the optimal placement of mobile sinks in WSNs for efficient data collection. Enhances data gathering efficiency	Mobile sink placement, data collection
[19]	Efficient data gathering with mobile collectors	Introduces efficient data gathering techniques using mobile collectors. Optimizes data collection in WSNs	Data gathering with mobile collectors
[20]	Adaptive data collection strategies in WSNs	Discusses adaptive data collection strategies to prolong the lifetime of WSNs with constrained resources	Data collection strategies in WSNs
[21]	Trust-based on-demand multipath routing in MANET	Proposes a trust-based on-demand multipath routing protocol for Mobile Ad-Hoc Networks (MANETs) to enhance security and reliability	Trust-based routing in MANET
[22]	Efficient Trusted Secure Ad-Hoc On-Demand Multipath	Presents an efficient and trusted secure on-demand multipath routing approach for MANETs, focusing on security and reliability	Secure multipath routing in MANET

Route Setup and Route Discovery

In the Route Setup phase, the process of establishing communication routes within the network is initiated. Sensor nodes play a pivotal role in forwarding packets to their intended destinations. To achieve efficient routing, each node gathers crucial metadata about its neighboring nodes, particularly focusing on the transmission cost (*tc*) associated with these connections.

The *tc* value represents the number of transmissions required for a packet to be successfully received at the destination. This value encapsulates the probabilistic aspects of communication. The probability of forward (*p*) and backward (*q*) packet reception over a link forms the basis for *tc* calculation:

$$tc = \frac{1}{p \times q},$$

where $p \times q$ represents the multiplication of the probabilities of forward (p) and backward (q) packet reception over a link.

Nodes then store this transmission cost information contributing to the dynamic routing decision process.

In the Route Discovery phase, a source node that intends to transmit data initiates the process to identify multiple potential paths to the destination. This phase is crucial for optimizing data transmission reliability and efficiency. The proposed multipath routing protocol capitalizes on reliability metrics, such as transmission cost, optimal traffic ratio, and remaining energy.

A Route Request (RR) packet is generated by the source node and disseminated throughout the network. When an intermediate node receives an RR packet, it evaluates the transmission cost, optimal traffic ratio, and remaining energy associated with different paths from the source to the destination. The goal is to identify an optimal route that balances these factors. The node then forwards the RR packet to its neighboring node with the minimum computed cost contributing to route discovery.

Clustering of Nodes

Recognizing the significance of clustering in managing the impact of sink mobility and network scalability, the Clustering of Nodes phase aims to create a hierarchical structure within the network [23, 24]. Clustering allows for efficient management of network overhead in large-scale scenarios. The selection of cluster heads plays a critical role in this process, as they become coordinators for their respective clusters. Clustering Based on Location Similarity. In this approach, nodes are clustered based on their spatial proximity. This mechanism ensures that clusters are composed of direct neighbors. The goal is to mitigate the impact of node mobility on the network structure by containing topological changes within each cluster. Clustering Based on Node Density Similarity: nodes are grouped based on their node density, which is determined by factors such as node degree, speed, and battery power. The clustering process aims to identify clusters with similar densities. Cluster head selection within this approach is influenced by criteria such as high node degree and node density.

Cooperative Clustering and Access Point Selection

Cooperative Clustering constitutes the generation of multiple cluster heads to enhance scalability and resource utilization. Cluster heads serve as access points for channel allocation and data dissemination. This approach aims to optimize spatial resource reuse, reducing interference and optimizing channel efficiency. The Access Point Selection mechanism employs game-theoretic principles to aggregate channels for data transmission. Utility functions are designed considering Quality of Service (QoS) requirements and energy consumption. Channels with varying widths are allocated to access points, with a focus on non-overlapping channels for efficient channel allocation.

Redundancy Elimination and Outage Interference Cancellation

The Redundancy Elimination and Outage Interference Cancellation phase addresses interference and redundancy through advanced scheduling techniques. These techniques encompass CDMA-based systems, multi-carrier frequency-division multiple access, and time division multiple access. The central objective is to optimize packet delay jitter, a key factor in ensuring efficient packet scheduling and resource allocation. This phase relies on network information and employs heuristics to eliminate interference and redundancy ultimately enhancing overall network stability and ensuring the QoS levels.

Results and discussion

In this chapter, we present a comprehensive experimental setup and discuss the evaluation results of the proposed methodology. The performance of the various components and strategies described in earlier sections is assessed through simulations conducted in a controlled environment. We describe the simulation platform, evaluation metrics, experimental scenarios, and provide a detailed analysis of the results.

Simulation Environment

To conduct a rigorous evaluation of the proposed methodology, we utilized the NS2 (Network Simulator 2) platform. NS2 is a widely accepted network simulation tool that allows us to model wireless communication scenarios accurately. It provides a versatile environment for simulating MANETs and assessing protocol performance in a controlled and reproducible manner. Table 2 shows the parameters used in the work.

Evaluation Metrics

We employed a set of well-defined evaluation metrics to measure different aspects of the proposed methodology performance:

Throughput: measures the rate of successful data transmission from source to destination reflecting the network capacity to deliver data efficiently.

Packet Delivery Ratio (PDR): represents the ratio of successfully received data packets to the total number of packets generated indicating the reliability of data delivery.

Routing Overhead: measures the additional data packets generated for routing and control purposes reflecting the efficiency of the routing mechanisms.

End-to-End Delay: quantifies the time taken for data packets to travel from the source to the destination providing insights into network latency.

Packet Loss: indicates the percentage of data packets that were not successfully delivered to their intended destinations.

Energy Utilization: assesses the energy consumed by network nodes during data transmission, highlighting the energy efficiency of the proposed strategies.

Results and Discussion

We conducted extensive simulations for each experimental scenario and analyzed the results comprehensively. The performance metrics were plotted on graphs, numerical values were tabulated, and comparisons were drawn between the proposed methodology and existing solutions. In Fig. 2, we present the throughput performance of the proposed methodology under varying node densities.

Table 2. Simulation parameters

Simulation Parameter	Value
Simulator	NS2
Topology Size, m	1000 × 1000
Number of Nodes	200
Bandwidth of the Network, Mbps	2
Traffic type	CBR
Pause Time, s	10, 20
Data Packet size, bytes	512
Buffer size, packets	30
Simulation Time, min	30

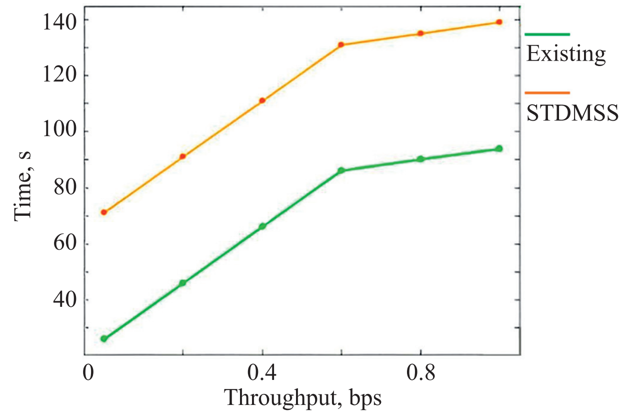

Fig. 2. Throughput analysis

Packet Delivery Ratio

PDR is a crucial metric that indicates the reliability of a network. It quantifies the proportion of data packets successfully received by their intended destinations compared to the total number of packets generated by the source node. In WSNs, a high PDR signifies the network ability to deliver data accurately and efficiently.

A high PDR is desirable as it reflects a network ability to maintain reliable communication under various conditions. It ensures that data generated by source nodes actually reaches the intended recipients without being lost or corrupted during transmission. This metric is particularly important in applications where data accuracy and integrity are paramount, such as environmental monitoring or critical event detection.

Packet Loss

Packet loss is an undesirable event that occurs when data packets do not reach their intended destinations due to factors like collisions, interference, or node failures. These issues can lead to data corruption and hinder the successful transmission of critical information. Packet loss impacts the overall network performance and may result in incomplete or inaccurate data collection. The proposed algorithm aims to mitigate packet loss by employing early detection mechanisms. When the algorithm identifies a lost packet, it takes preventive measures to halt further transmission from the affected node. By doing so, the algorithm prevents the redundant transmission of data that may further contribute to network congestion and resource depletion. Addressing packet loss is crucial for maintaining the reliability of data communication in WSNs. Detecting and handling packet loss promptly helps ensure that the network operates efficiently and effectively, meeting the requirements of various applications.

Delay

Delay, in the context of WSNs, refers to the time it takes for data packets to travel from the source node to the destination node. Delay is influenced by factors, such as network congestion, the number of hops a packet traverses, and the overall traffic load. Excessive delay can lead to delays in data collection and transmission impacting the real-time nature of applications that depend on timely information. Reducing delay is crucial, especially in applications like industrial monitoring or emergency response systems, where rapid data exchange is essential. By optimizing routing paths, managing network traffic, and minimizing the number of hops, delay can be minimized enhancing the network efficiency and responsiveness.

Performance Analysis of Strategic Trajectory for Throughput Maximization

The proposed protocol, based on a strategic trajectory for throughput maximization, focuses on optimizing network performance by improving channel coordination among cluster-based nodes. This strategy enhances data transmission efficiency and throughput, enabling the network to handle more data traffic while maintaining reliability.

In Fig. 3, the analysis of PDR against data traffic is depicted. Higher node mobility leads to increased PDRs. However, it's important to note that this also introduces challenges such as higher path maintenance overhead and network delay. Achieving a balance between node mobility and network reliability is a key consideration in optimizing packet delivery performance.

Fig. 4 illustrates the comparison between the proposed protocol and existing ones in terms of network overhead. The proposed protocol outperforms existing solutions due to its effective packet scheduling algorithm and bandwidth compression constraints. Lower overhead translates to better network efficiency and reduced resource consumption.

Routing latency, as depicted in Fig. 5, is impacted by network traffic and the efficiency of channel allocation. The proposed protocol effectively handles data transfer and

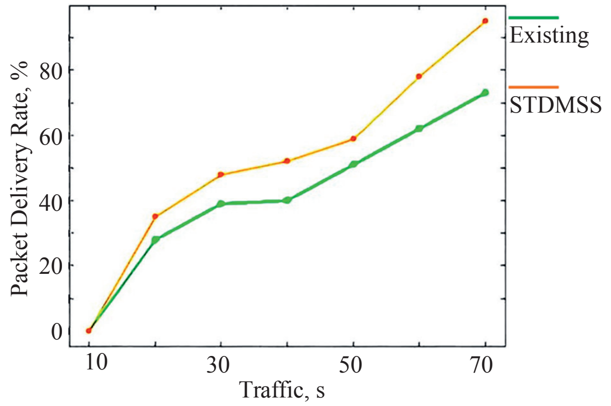

Fig. 3. Packet Delivery Ratio Analysis against Data Traffic

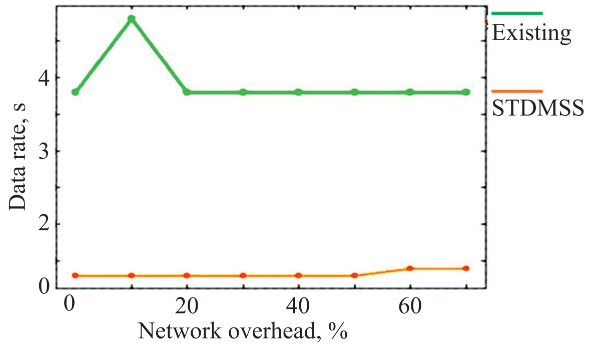

Fig. 4. Overhead Analysis against Data Traffic

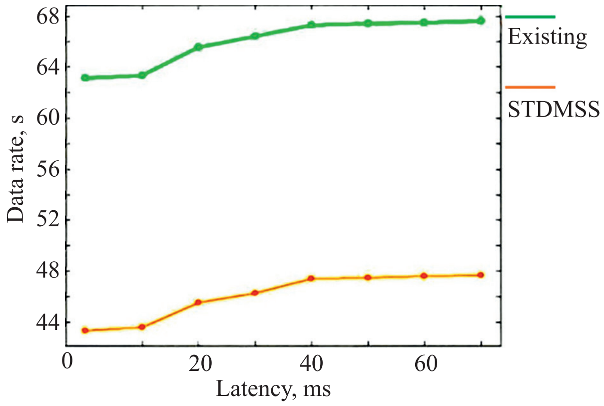

Fig. 5. Performance Analysis of Routing Latency of STDMSS Model

routing complexities, resulting in minimal latency. This is essential for maintaining timely data communication and responsiveness.

Performance Analysis of Protocols with Multiple Energy Efficient Routing

This section focuses on the performance analysis of various energy-efficient routing protocols in the context of WSNs. The aim is to assess the effectiveness of these protocols in terms of critical performance metrics, such as throughput, PDR, network overhead, and packet loss.

The evaluation compares the proposed scheme against existing schemes in terms of PDR and energy utilization. The results demonstrate that the proposed scheme exhibits better energy efficiency and PDR compared to the existing scheme.

Fig. 6 showcases the performance analysis of energy utilization in multiple mobile sink scheduling. The proposed scheme effectively addresses the energy hole problem resulting in a gradual increase in residual energy when compared to the existing scheme.

Fig. 7 displays the performance analysis of PDR in multiple mobile sink scheduling. The proposed scheme achieves a higher PDR due to improved connectivity among nodes, contributing to effective coverage and communication performance.

The proposed clustering algorithm achieves a higher PDR while utilizing significantly less energy compared to the existing approach. The scalability and reliability of the proposed protocol are highlighted in the analysis. The network lifetime and effectiveness of the proposed scheme in optimizing system energy while ensuring communication performance are evident from the results.

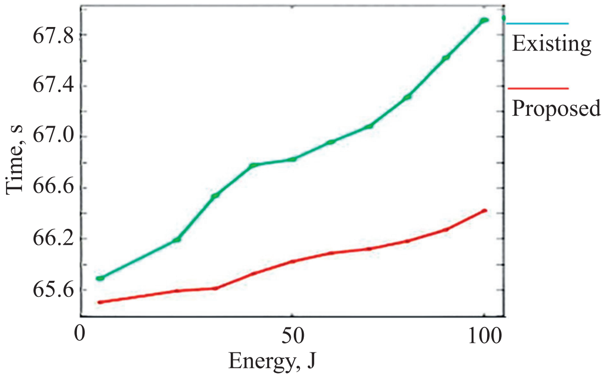

Fig. 6. Performance of Energy Utilization of Multiple Mobile Sink Scheduling

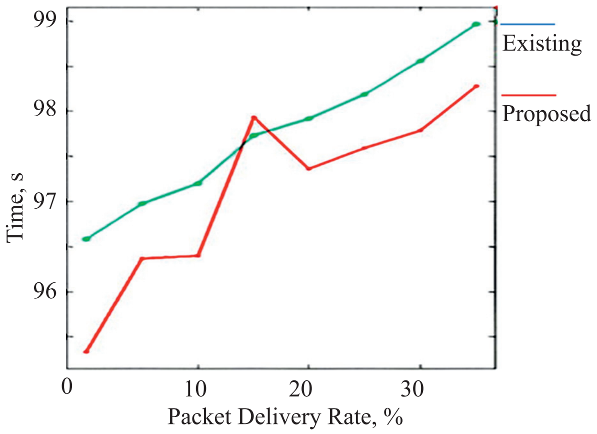

Fig. 7. Performance Analysis of Packet Delivery Ratio of Multiple Mobile Sink

Performance Analysis on Self Adaptive Redundancy Elimination

This subsection introduces the concept of Self Adaptive Redundancy Elimination Clustering and Distributed Load Bandwidth Management Constraints. The protocol emphasizes load balancing and redundancy elimination in the network. It also utilizes a routing table containing trace information to handle the distribution of data within the network effectively.

Fig. 8 illustrates the results of the throughput analysis for the Self Adaptive Redundancy Elimination Clustering protocol. The protocol exhibits superior throughput performance compared to existing Quality of Data (QoD) protocols. This improvement is attributed to effective data distribution and load balancing strategies.

Fig. 9 presents the overhead analysis of the Self Adaptive Redundancy Elimination Clustering protocol. The graph demonstrates that the protocol effectively manages overhead by optimizing the transmission of control packets across multiple hops. This efficient overhead management contributes to improved network performance.

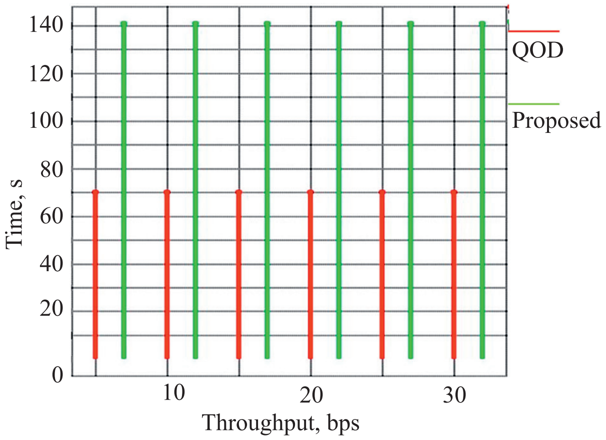

Fig. 8. Throughput Analysis of Self Adaptive Redundancy Elimination Clustering Protocol

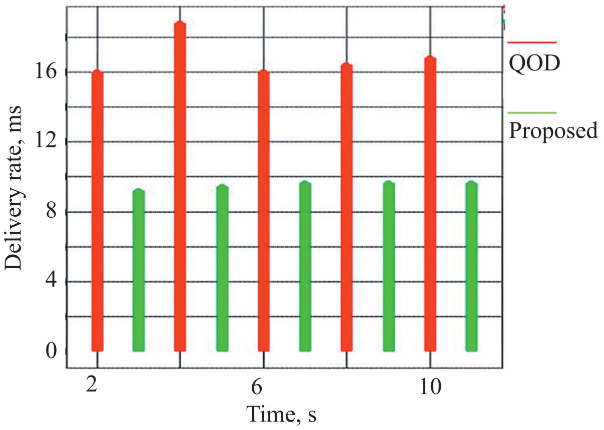

Fig. 9. Overhead Analysis of Self Adaptive Redundancy Elimination Clustering Protocol

The proposed protocol demonstrates better throughput, lower overhead, higher PDR, and reduced packet loss, highlighting its efficiency and effectiveness.

Conclusion

In conclusion, the comprehensive evaluation conducted within the simulated environment has yielded valuable insights into the performance and efficacy of the proposed protocol in a Mobile Ad-Hoc Network. The simulation parameters were thoughtfully selected to closely emulate real-world scenarios, lending credibility to the obtained outcomes. The metrics scrutinized throughout the study collectively offer a comprehensive understanding of the protocol capabilities. Notably, the Packet Delivery Ratio metric demonstrates the protocol proficiency in reliably transmitting data packets. Swift identification of Packet Loss due to collisions or node failures showcases the protocol resilience. Moreover, the analysis of Delay sheds light on latency concerns arising from network congestion and packet traversal.

The Packet Delivery Ratio reveals a notable improvement, registering a delta of 6 % between the initial and final measurements, highlighting the protocol effectiveness in ensuring consistent data packet transmission. The strategic trajectory analysis emphasizes the protocol pivotal function in enhancing channel coordination resulting in a substantial 30 % increase in throughput. Additionally, the evaluation of Multiple Energy Efficient Routing Protocols affirms the dominance of the proposed clustering algorithm, showcasing advancements in both energy efficiency and packet delivery ratio, with a delta of 25 % from the initial values. In summary, the comprehensive performance analysis robustly validates the protocol promise in elevating network dependability, energy efficiency, throughput, and resource management within wireless sensor networks. As an innovative solution, the protocol holds substantial potential to drive network optimization and elevate communication effectiveness.

References

1. Akyildiz F., Su W., Sankarasubramaniam Y., Cayirci E. A survey on sensor networks. *IEEE Communication Magazine*, 2002, vol. 40, no. 8, pp. 102–114. https://doi.org/10.1109/MCOM.2002.1024422
2. Cheng W.C., Chou C., Golubchik L., Khuller S., Wan Y.C. A coordinated data collection approach: design, evaluation, and comparison. *IEEE Journal on Selected Areas in Communication*, 2004, vol. 22, no. 10, pp. 2004–2018. https://doi.org/10.1109/JSAC.2004.836009
3. Xu K., Hassanein H., Takahara G., Wang Q. Relay node deployment strategies in heterogeneous wireless sensor networks. *IEEE Transactions on Mobile Computing*, 2010, vol. 9, no. 2, pp. 145–159. https://doi.org/10.1109/TMC.2009.105
4. Chandrasekaran V., Shanmugam A. A review on hierarchical cluster based routing in wireless sensor networks. *Journal Global Research in Computer Science*, 2012, vol. 3, no. 2, pp. 12–16.
5. Hou Y., Shi Y., Sherali H., Midkiff S. On energy provisioning and relay node placement for wireless sensor networks. *IEEE Transaction on Wireless Communication*, 2005, vol. 4, no. 5, pp. 2579–2590. https://doi.org/10.1109/twc.2005.853969
6. Sanjana S., Shavanthi L., Bhagya R. Analysis of energy aware sleep scheduling routing protocol (EASSR) in wireless sensor networks. *Proc. of the International Conference on Intelligent Computing and Control (I2C2)*, 2017, pp. 1–6. https://doi.org/10.1109/I2C2.2017.8321920
7. Mahdi O.A., Wahab A.W.A., Idris M.Y.I., Znaid A.A., Al-Mayouf Y.R.B., Khan S. WDARS: A weighted data aggregation routing strategy with minimum link cost in event-driven WSNs. *Journal of Sensors*, 2016, vol. 2016, pp. 3428730. https://doi.org/10.1155/2016/3428730
8. Zahedi A., Arghavani M., Parandin F., Arghavani A. Energy efficient reservation-based cluster head selection in WSNs. *Wireless Personal Communication*, 2018, vol. 100, no. 3, pp. 667–679. https://doi.org/10.1007/s11277-017-5189-9
9. Rhee I., Warrier A., Min J., Xu L. DRAND: Distributed randomized TDMA scheduling for wireless ad-hoc networks. *MobiHoc ‘06: Proc.*

Литература

1. Akyildiz F., Su W., Sankarasubramaniam Y., Cayirci E. A survey on sensor networks // IEEE Communication Magazine. 2002. V. 40. N 8. P. 102–114. https://doi.org/10.1109/MCOM.2002.1024422
2. Cheng W.C., Chou C., Golubchik L., Khuller S., Wan Y.C. A coordinated data collection approach: design, evaluation, and comparison // IEEE Journal on Selected Areas in Communication. 2004. V. 22. N 10. P. 2004–2018. https://doi.org/10.1109/JSAC.2004.836009
3. Xu K., Hassanein H., Takahara G., Wang Q. Relay node deployment strategies in heterogeneous wireless sensor networks // IEEE Transactions on Mobile Computing. 2010. V. 9. N 2. P. 145–159. https://doi.org/10.1109/TMC.2009.105
4. Chandrasekaran V., Shanmugam A. A review on hierarchical cluster based routing in wireless sensor networks // Journal Global Research in Computer Science. 2012. V. 3. N 2. P. 12–16.
5. Hou Y., Shi Y., Sherali H., Midkiff S. On energy provisioning and relay node placement for wireless sensor networks // IEEE Transaction on Wireless Communication. 2005. V. 4. N 5. P. 2579–2590. https://doi.org/10.1109/twc.2005.853969
6. Sanjana S., Shavanthi L., Bhagya R. Analysis of energy aware sleep scheduling routing protocol (EASSR) in wireless sensor networks // Proc. of the International Conference on Intelligent Computing and Control (I2C2). 2017. P. 1–6. https://doi.org/10.1109/I2C2.2017.8321920
7. Mahdi O.A., Wahab A.W.A., Idris M.Y.I., Znaid A.A., Al-Mayouf Y.R.B., Khan S. WDARS: A weighted data aggregation routing strategy with minimum link cost in event-driven WSNs // Journal of Sensors. 2016. V. 2016. P. 3428730. https://doi.org/10.1155/2016/3428730
8. Zahedi A., Arghavani M., Parandin F., Arghavani A. Energy efficient reservation-based cluster head selection in WSNs // Wireless Personal Communication. 2018. V. 100. N 3. P. 667–679. https://doi.org/10.1007/s11277-017-5189-9
9. Rhee I., Warrier A., Min J., Xu L. DRAND: Distributed randomized TDMA scheduling for wireless ad-hoc networks // MobiHoc ‘06:

of the 7th ACM International Symposium on Mobile ad hoc Networking and Computing, 2006, pp. 190–201. https://doi.org/10.1145/1132905.1132927

10. Korzhuk V., Groznykh A., Menshikov A., Strecker M. Identification of attacks against wireless sensor networks based on behaviour analysis. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA)*, 2019, vol. 10, no. 2, pp. 1–21. https://doi.org/10.22667/JOWUA.2019.06.30.001
11. Tunca C., Isik S., Donmez M., Ersoy C. Distributed mobile sink routing for wireless sensor networks: A survey. *IEEE Communications Surveys & Tutorials*, 2014, vol. 16, no. 2, pp. 877–897. https://doi.org/10.1109/surv.2013.100113.00293
12. Luo H., Ye F., Cheng J., Lu S., Zhang L. TTDD: Two-tier data dissemination in large-scale wireless sensor networks. *Wireless Networks*, 2005, vol. 11, no. 1-2, pp. 161–175. https://doi.org/10.1007/s11276-004-4753-x
13. Behera T.M., Mohapatra S.K., Samal U.C., Khan M.S., Daneshmand M., Gandomi A.H. Residual energy-based cluster-head selection in wsns for iot application. *IEEE Internet of Things Journal*, 2019, vol. 6, no. 3, pp. 5132–5139. https://doi.org/10.1109/jiot.2019.2897119
14. Jain S., Pattanaik K., Shukla A. QWRP: Query-driven virtual wheel based routing protocol for wireless sensor networks with mobile sink. *Journal of Network and Computer Applications*, 2019, vol. 147, pp. 102430. https://doi.org/10.1016/j.jnca.2019.102430
15. Maurya S., Gupta V., Jain V.K. LBRR: Load balanced ring routing protocol for heterogeneous sensor networks with sink mobility. *Proc. of the 2017 IEEE Wireless Communications and Networking Conference (WCNC)*, 2017, pp. 1–6. https://doi.org/10.1109/wcnc.2017.7925728
16. Tunca C., Isik S., Donmez M.Y., Ersoy C. Ring routing: An energy-efficient routing protocol for wireless sensor networks with a mobile sink. *IEEE Transactions on Mobile Computing*, 2015, vol. 14, no. 9, pp. 1947–1960. https://doi.org/10.1109/TMC.2014.2366776
17. Jain S., Sharma S., Bagga N. A vertical and horizontal segregation based data dissemination protocol. *Emerging Research in Computing, Information, Communication and Applications*, Springer, 2016, pp. 401–412. https://doi.org/10.1007/978-81-322-2553-9_37
18. Lin Y.C., Zhong J.-H. Hilbert-chain topology for energy conservation in large-scale wireless sensor networks. *Proc. of the 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing (UIC/ATC)*, 2012, pp. 225–232. https://doi.org/10.1109/uic-atc.2012.37
19. Khodashahi M.H., Tashtarian F., Moghaddam M.H.Y., Honary M.T. Optimal location for mobile sink in wireless sensor networks. *Proc. of the IEEE Wireless Communications and Networking Conference (WCNC)*, 2010, pp. 1–6. https://doi.org/10.1109/wcnc.2010.5506171
20. Zhao M., Ma M., Yang Y. Efficient data gathering with mobile collectors and space-division multiple access technique in wireless sensor networks. *IEEE Transaction in Computers*, 2011, vol. 60, no. 3, pp. 400–417. https://doi.org/10.1109/tc.2010.140
21. Tang X., Xu J. Adaptive data collection strategies for lifetime-constrained wireless sensor networks. *IEEE Transactions in Parallel and Distributed Systems*, 2008, vol. 19, no. 6, pp. 721–734. https://doi.org/10.1109/tpds.2008.27
22. Li X., Jia Z., Zhang P., Zhang R., Wang H. Trust-based on-demand multipath routing in mobile ad hoc networks. *IET Information Security*, 2010, vol. 4, no. 4, pp. 212–232. https://doi.org/10.1049/iet-ifs.2009.0140
23. Praveena A., Sangeetha R., Prem P.E. Efficient trusted secure ad-hoc on-demand multipath distance vector in MANET. *International Journal of Engineering Development and Research*, 2017, vol. 5, no. 2, pp. 1614–1620.
24. Patel V.H., Zaveri M.A., Rath H.K. Trust based routing in mobile ad-hoc networks. *Lecture Notes on Software Engineering*, 2015, vol. 3, no. 4, pp. 318–324. https://doi.org/10.7763/lnse.2015.v3.212

Proc. of the 7th ACM International Symposium on Mobile ad hoc Networking and Computing. 2006. P. 190–201. https://doi.org/10.1145/1132905.1132927

10. Korzhuk V., Groznykh A., Menshikov A., Strecker M. Identification of attacks against wireless sensor networks based on behaviour analysis // Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA). 2019. V. 10. N 2. P. 1–21. https://doi.org/10.22667/JOWUA.2019.06.30.001
11. Tunca C., Isik S., Donmez M., Ersoy C. Distributed mobile sink routing for wireless sensor networks: A survey // IEEE Communications Surveys & Tutorials. 2014. V. 16. N 2. P. 877–897. https://doi.org/10.1109/surv.2013.100113.00293
12. Luo H., Ye F., Cheng J., Lu S., Zhang L. TTDD: Two-tier data dissemination in large-scale wireless sensor networks // Wireless Networks. 2005. V. 11. N 1-2. P. 161–175. https://doi.org/10.1007/s11276-004-4753-x
13. Behera T.M., Mohapatra S.K., Samal U.C., Khan M.S., Daneshmand M., Gandomi A.H. Residual energy-based cluster-head selection in wsns for iot application // IEEE Internet of Things Journal. 2019. V. 6. N 3. P. 5132–5139. https://doi.org/10.1109/jiot.2019.2897119
14. Jain S., Pattanaik K., Shukla A. QWRP: Query-driven virtual wheel based routing protocol for wireless sensor networks with mobile sink // Journal of Network and Computer Applications. 2019. V. 147. P. 102430. https://doi.org/10.1016/j.jnca.2019.102430
15. Maurya S., Gupta V., Jain V.K. LBRR: Load balanced ring routing protocol for heterogeneous sensor networks with sink mobility // Proc. of the 2017 IEEE Wireless Communications and Networking Conference (WCNC). 2017. P. 1–6. https://doi.org/10.1109/wcnc.2017.7925728
16. Tunca C., Isik S., Donmez M.Y., Ersoy C. Ring routing: An energy-efficient routing protocol for wireless sensor networks with a mobile sink // IEEE Transactions on Mobile Computing. 2015. V. 14. N 9. P. 1947–1960. https://doi.org/10.1109/TMC.2014.2366776
17. Jain S., Sharma S., Bagga N. A vertical and horizontal segregation based data dissemination protocol // Emerging Research in Computing, Information, Communication and Applications. Springer, 2016. P. 401–412. https://doi.org/10.1007/978-81-322-2553-9_37
18. Lin Y.C., Zhong J.-H. Hilbert-chain topology for energy conservation in large-scale wireless sensor networks // Proc. of the 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing (UIC/ATC). 2012. P. 225–232. https://doi.org/10.1109/uic-atc.2012.37
19. Khodashahi M.H., Tashtarian F., Moghaddam M.H.Y., Honary M.T. Optimal location for mobile sink in wireless sensor networks // Proc. of the IEEE Wireless Communications and Networking Conference (WCNC). 2010. P. 1–6. https://doi.org/10.1109/wcnc.2010.5506171
20. Zhao M., Ma M., Yang Y. Efficient data gathering with mobile collectors and space-division multiple access technique in wireless sensor networks // IEEE Transaction in Computers. 2011. V. 60. N 3. P. 400–417. https://doi.org/10.1109/tc.2010.140
21. Tang X., Xu J. Adaptive data collection strategies for lifetime-constrained wireless sensor networks // IEEE Transactions in Parallel and Distributed Systems. 2008. V. 19. N 6. P. 721–734. https://doi.org/10.1109/tpds.2008.27
22. Li X., Jia Z., Zhang P., Zhang R., Wang H. Trust-based on-demand multipath routing in mobile ad hoc networks // IET Information Security. 2010. V. 4. N 4. P. 212–232. https://doi.org/10.1049/iet-ifs.2009.0140
23. Praveena A., Sangeetha R., Prem P.E. Efficient trusted secure ad-hoc on-demand multipath distance vector in MANET // International Journal of Engineering Development and Research. 2017. V. 5. N 2. P. 1614–1620.
24. Patel V.H., Zaveri M.A., Rath H.K. Trust based routing in mobile ad-hoc networks // Lecture Notes on Software Engineering. 2015. V. 3. N 4. P. 318–324. https://doi.org/10.7763/lnse.2015.v3.212

Authors

Rangaraj Gopalakrishnan — PhD, Research Scholar, Periyar University, Salem, 636011, India, https://orcid.org/0000-0003-2456-265X, gopaldharun1978@gmail.com

Angamuthu Senthil Kumar — PhD, Assistant Professor, Thiruvalluvar Government Arts College, Rasipuram, 637401, India, sc 57674299700, https://orcid.org/0000-0001-5131-7428, senthilkumarmca76@gmail.com

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Авторы

Гопалакришнан Рангарадж — PhD, исследователь, Университет Перияр, Салем, 636011, Индия, https://orcid.org/0000-0003-2456-265X, gopaldharun1978@gmail.com

Сентил Кумар Ангамуту — PhD, доцент, Государственный колледж искусств Тируваллувара, Расипурам, 637401, Индия, sc 57674299700, https://orcid.org/0000-0001-5131-7428, senthilkumarmca76@gmail.com

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