Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 12, No. 4, December 2024, pp. 991~1004
ISSN: 2089-3272, DOI: 10.52549/ijeei.v12i4.5814

Empirical Evaluation of Energy-assisted Protocols for Wireless Sensor Networks

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Article Info

Article history:

Received Aug 10, 2024
Revised Nov 5, 2024
Accepted Nov 20, 2024

Keywords:

Energy consumption;
Energy-efficient-backbone;
Load balancing;
Sensor nodes;
Wireless Sensor Network.

ABSTRACT

Wireless sensor networks (WSNs) have emerged as a transformative technology with widespread applications in various fields, such as environmental monitoring, healthcare, and industrial automation. This investigation provides a comprehensive evaluation and comparison of an existing protocol, the Energy-Efficient Backbone-assisted protocol for Load Balancing (EBLBP), against two established protocols: Ad-hoc On-Demand Distance Vector (AODV) and Destination Sequenced Distance Vector (DSDV). Through extensive simulations, we analyzed the performance of these protocols across four critical metrics: scalability, efficiency, network lifetime, and energy consumption. Our findings reveal the inherent strengths and weaknesses of EBLBP, AODV, and DSDV, offering insights into their suitability for various WSN deployment scales and conditions. In the simulation environment, EBLBP achieved an impressive 66.67% reduction in overall energy consumption of 100 to 600 node positions, which underlined its positive impact on energy efficiency. The NS2 simulator was used for this investigation. The measured results validate the advantages of EBLBP in terms of energy optimization.

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1. INTRODUCTION

In the dynamic and ever-evolving field of Wireless Sensor Networks (WSNs), the efficiency and sustainability of network protocols play a critical role in determining the overall performance and viability of these systems. Among the myriad of protocols developed over the years, the Energy-Efficient Backbone Assisted Protocol for Load Balancing (EBLBP) [3, 4, 12] stands out as a notable contribution for enhancing the energy management and operational lifespan of WSNs [1]. EBLBP has garnered attention for its innovative approach for balancing load and conserving energy across network nodes. This feature is particularly crucial in large-scale WSN deployments with limited or unevenly distributed energy resources.

The present study aims to delve deeply into the EBLBP framework, employing the NS2 simulator to rigorously assess its performance against established protocols such as the Ad-hoc On-Demand Distance Vector (AODV) [2] and Destination Sequenced Distance-Vector (DSDV) [2]. By focusing on key performance metrics such as scalability, efficiency, network lifetime, and energy consumption, the research seeks to provide an understanding of EBLBP's operational effectiveness and its potential to optimize energy usage in WSNs. The goal is to clarify the strengths and limitations of EBLBP within WSN applications, offering insights that could guide future developments and enhancements for energy-efficient network design and its implementation. This research does not endeavor to create a new protocol from scratch; rather, it focuses on a comprehensive investigation of the existing and well established EBLBP protocol in WSNs.

Energy-Efficient Backbone-assisted Protocol for Load Balancing (EBLBP)

Investigating the EBLBP involves in understanding its performance in terms of a tree-based network structure, balancing energy consumption, and models for reselecting sink nodes [3] as described under:
Tree-Based Network: EBLBP often leverages a tree-based network structure, where sensor nodes organize themselves in a hierarchical tree topology. This structure facilitates efficient communication and data aggregation, allowing for a streamlined flow of information towards a central point in the network. The tree-based network reduces communication latency by minimizing the hops data needs to traverse to reach the sink node. The hierarchical structure supports scalability, enabling the network to efficiently handle the increasing sensor nodes without compromising its performance. The tree structure helps in aggregating data at different levels, optimizing the use of bandwidth, and reducing redundant transmissions [4].

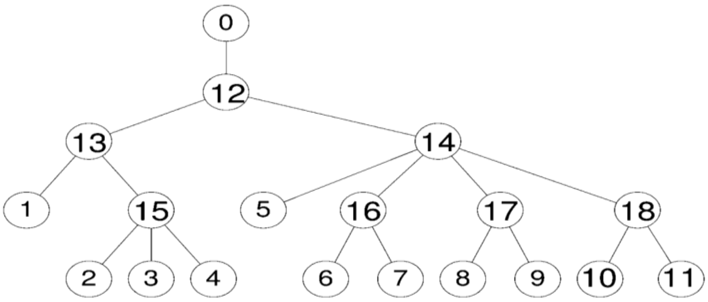

Figure 1. Logical tree topology for the network used in computer simulations

Balanced Energy Consumption: The EBLBP aims to balance energy consumption among sensor nodes to prevent premature depletion of individual nodes and ensure a prolonged network lifetime. Load balancing mechanisms and intelligent task allocation are utilized to accomplish this goal. Balancing energy consumption prevents a few nodes from exhausting their energy quickly, which leads to a more balanced distribution of the tasks and, consequently, a longer overall network lifetime. Energy balance reduces the risk of individual node failures, which improves overall reliability and network stability. By avoiding energy disparities, the network operates more efficiently thus ensuring a continuous and sustainable flow of data.

Reselection of Sink Node Models: This involves periodically changing the central node that aggregates data from the sensor nodes thus optimizing energy consumption and load distribution. Reselecting the sink node prevents uneven energy consumption, which guarantees that no single node consistently handles the role of the sink, hence contributing to load balancing. Sink node reselection models enable the network to adapt to the changing conditions, including variations in sensor node energy levels, environmental dynamics, and communication patterns. The ability to dynamically reselect the sink node improves network's robustness, making it more resilient to node failures, environmental changes, and dynamic application requirements [5].

Eblbp vs Routing Protocols AODV and DSDV

In the ever-evolving field of WSNs, the choice of routing protocols significantly influences the efficiency and adaptability of the network. Among the prominent protocols, Ad-Hoc On-Demand Distance Vector (AODV) [2, 4], and Destination-Sequenced Distance Vector (DSDV) [2, 11] represent divergent strategies to address the multifaceted challenges inherent in WSNs. The EBLBP [1] with its emphasis on energy efficiency and load balancing, it seeks to optimize resource utilization and extend network lifespan. EBLBP dynamically redistributes nodes based on fitness criteria, contributing to an overall reduction in energy consumption and efficient task allocation. On the contrary, AODV operates as an on-demand, reactive protocol that establishes routes only when needed. It excels in dynamic environments by minimizing routing overhead and adapting swiftly to changing network topologies. The notable features of AODV include route discovery and maintenance mechanisms, making it suitable for WSN scenarios characterized by intermittent communication needs [2]. The DSDV being a proactive distance-vector protocol, maintains a consistent, up-to-date routing table through periodic updates. Its use of sequence numbers guarantees route freshness, making it particularly robust in stable network conditions. However, the periodic updates can introduce overhead, potentially impacting energy efficiency [11].

The comparative analysis between EBLBP, AODV, and DSDV will highlight their respective strengths and limitations in WSNs. Considerations will include energy conservation, adaptability to dynamic network conditions, routing efficiency, and the trade-offs inherent in their design principles.

Problem Statement

WSNs have gained significant importance in various applications, ranging from environmental monitoring to industrial automation. However, the limited energy resources of sensor nodes pose a critical challenge in ensuring the longevity and sustainability of these networks. EBLBP has been investigated to address this challenge. EBLBP offers promising solutions for enhancing energy efficiency and load balancing in WSNs. This research aims to asses the effectiveness of EBLBP in practical WSN deployments in terms of energy efficiency, load balancing, adaptability to dynamic environments, and its impact on network longevity. Additionally, it seeks to identify potential limitations and vulnerabilities that may affect EBLBP's robustness.

2. RELATED WORK

This section presents the pros and cons of the different existing protocols for WSNs. We examine how these protocols have changed and improved over time and their effects on network performance. Yakoi et al [6] have discussed some of the methods that help improve energy consumption, such as the mobility of nodes, clustering using the AELEACH protocol based on descriptors, the particle filter Figure for target trajectory, and the Gini index for energy efficiency estimation. AE-LEACH is the investigated Figure. The particle filter Figure is utilized to predict the target trajectory, yielding a better result and selectively activating the subsequent round of sensor nodes for continuous target tracking. The energy efficiency of the clustering Figure was calculated using the Gini index [4]. Hong et al [7] used the virtual backbone problem and the centralized approach to improve the efficiency and stability of WSNs. Kumar et al [8] investigated how to use cluster-based routing, compressive sensing (CS theory), load balancing, and sink placement to increase load balancing and enhance network lifetime in WSNs. Begum et al [9] explored how to select the control nodes for the heterogeneous software-defined wireless sensor network (SDWSN) that considers the energy heterogeneity of its sensors. Genetic mutation-based particle swarm optimization (GMPSO) is one of the nature-inspired routing techniques. Krishna et al [10] have discussed alternatives to some of the currently used IoT routing protocols and provides more routing options. they examined the routing protocols of Ad-Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), and Optimized Link State Routing (OLSR) applications to the wireless sensor networks.

Table 1. Comparison between EBLBP and other related works

No	Features investigated	Ref. [6]	Ref. [7]	Ref. [8]	Ref. [9]	Ref. [10]
1	Energy optimization	Y	Y	Y	Y	Y
2	Load balancing	N	Y	Y	N	N
3	Dynamic network adaptation	Y	Y	Y	Y	Y
4	Fault tolerance	Y	N	Y	Y	N
5	Scalability	Y	N	Y	Y	Y
6	Traffic prediction	Y	N	N	N	N
7	QOS-awareness	N	N	Y	Y	N
8	Distributed decision-making	Y	Y	Y	Y	Y
9	Network security	N	N	N	N	Y
10	Adopting clustering structure	N	Y	Y	Y	Y
11	Intrusion tolerance	N	N	N	N	Y
12	Degree saturation	Y	N	Y	Y	Y
	Total	7	5	9	8	8

The AODV operates as an on-demand, reactive protocol that establishes routes only when needed. It excels in dynamic environments by minimizing routing overhead and adapting swiftly to changing network topologies. The notable features of AODV include route discovery and maintenance mechanisms, making it suitable for WSN scenarios characterized by intermittent communication needs [3]. The DSDV, a proactive distance-vector protocol, maintains a consistent, up-to-date routing table through periodic updates. Its use of sequence numbers guarantees route freshness, making it particularly robust in stable network conditions. However, the periodic updates can introduce overhead, potentially impacting energy efficiency [10]. We have extracted the features from the other related work [6, 10] and cross-list with references in Table 1. All these twelve features will be considered for incorporation into investigation of EBLBP.

3. ENERGY-EFFICIENT BACKBONE ASSISTED PROTOCOL

Commonly adopted hierarchical routing protocols, such as Ad-Hoc On-Demand Distance Vector (AODV) and Destination Sequenced Distance Vector (DSDR) have been utilized to improve energy efficiency. However, these protocols still need improved energy efficiency, load balancing, and a longer lifetime. For instance, when nodes increase in AODV and DSDV routing protocols, network performance deteriorates, and energy consumption is not considered during routing. Consequently, more dependable network models and routing Figures are required for sensors in WSNs [3, 11]. The network consists of three types of nodes: backbone nodes (BN), non-backbone nodes (NBN), and a special node known as the head backbone node (HBN), which is active at a high energy level. The network formation is initiated by HBN, which sends broadcast packets to locate eligible BNs. Non-backbone nodes retain the broadcast packet and calculate the fitness factor of backbone nodes. The fitness factor is a metric or score that assesses the suitability or efficiency of backbone nodes [12, 13].

NS2 is utilized to simulate the investigated Figure, which has three functions: building a tree-based self-organized network, load balancing based on energy consumption, and reselection of sink nodes. The parameter used to measure the network life and reorganization of backbone nodes is based on the hop, distance, left energy, and child node with the investigated approach. Hop is measured between the backbone and sink nodes based on the last hop. Distance is based on the minimum value between the backbone and sink nodes. Left energy is determined from the residual energy of the backbone node. The number of child nodes for each backbone node is shown using child number and based on the backbone node maximum child nodes [4].

3.1 EBLBP Figures

The investigated EBLBP consists of four sub algorithms which are:

i) Best Backbone Node Selection as shown in Figure 1 [3, 12]
ii) How the NBN joins the BN in the WSN as shown in Figure 2 [4]
iii) Reorganization of Backbone node by child nodes as shown in Figure 3 [5]
iv) Managing the re-election and re-selection of nodes within the network, as shown in Figure 4 [6]

3.1.1 Best Backbone Node Selection

The Figure mainly focuses on evaluating and selecting nodes based on their fitness. It concentrates on selecting the backbone node (BN). The non-backbone nodes (NBN) initiate the network formation and join in the network node. To select the most energy-efficient sensor node in a WSN based on a fitness metric, each sensor node in the network is represented by an element in the `opt_BN` array. The initialization of `max_fitness` and `BN_index` to zero suggests the start of an evaluation process focused on energy efficiency [3].

The loop iterates through each sensor node, and for each node, a fitness value (`F`) is calculated. This fitness value could correspond to energy-related metrics, such as remaining battery capacity, or a combination of factors related to load balancing. The conditional statements within the loop compare the calculated fitness value (`F`) with the current maximum fitness (`max_fitness`). If the fitness of the current node is greater than the current maximum fitness, the code updates `max_fitness` and `BN_index` with the new values. This implies that the current node based on the criteria defined by the EBLBP [12] is considered as the most energy-efficient,. The selection of backbone node is based on the following equation:

$$Fi=\frac{\alpha}{Di}+\frac{\beta}{Ni+1}+\alpha Ei+\frac{\delta}{Hi+1} \tag{1}$$

where *Fi* indicates the node's fitness factor, *Ei* is the node's residual energy, *Di* is the distance between the current node and nodei, and *Ni* represents the number of nodei child nodes. The node hop is the root node hop of 0, and the other is their backbone node hop plus one. *Hi* denotes the hop of nodei. *A*, *β*, and *γ* are the normalized parameters for the four factors. Suppose that α=15, β=3, µ=1/20, and δ=11 are set to represent the following: the communication distance is α and 15 m maximum, the number of child nodes is β, the initial energy of node is 20J, and the number of hops to reach sink node is 10 [3].

This selection mechanism is crucial for optimizing the utilization of energy resources across the sensor nodes. EBLBP aims to distribute tasks and data processing effectively among nodes to prevent premature energy depletion in specific nodes. The best backbone node selection Figure is a part of the process that identifies and records the sensor node that best satisfies the energy efficiency criteria defined by the EBLBP. The Figure flow chart is shown in Figure 2.

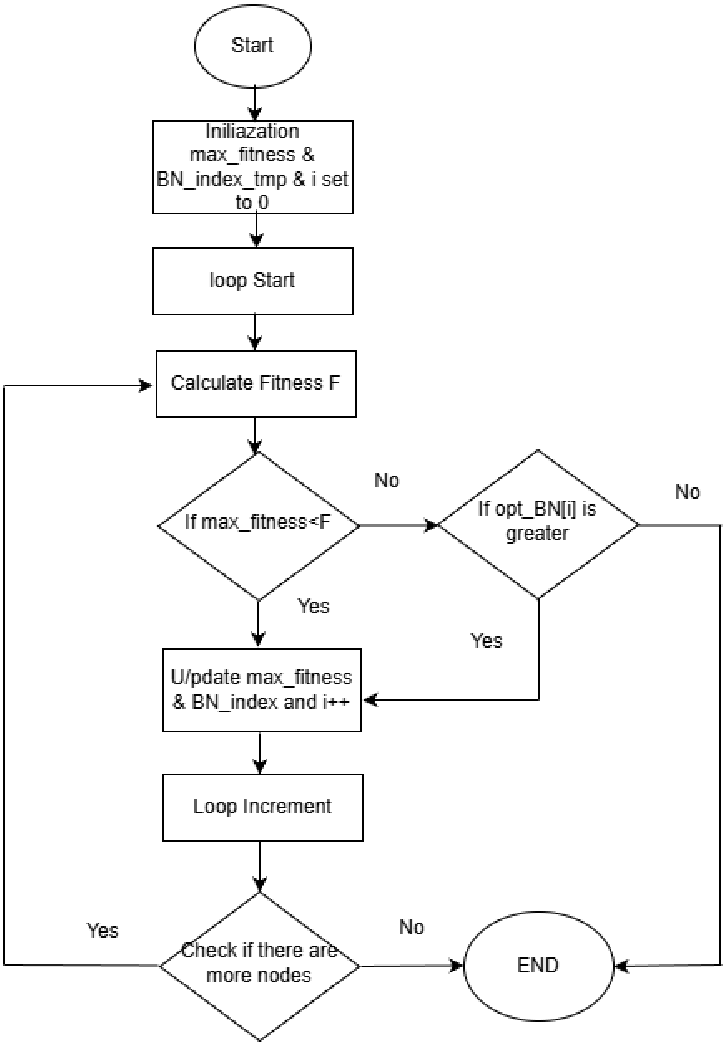

Figure 2. Best backbone selection flowchart

3.1.2 How the NBN joins the BN in the WSN

Figure 2 shows how the non-backbone node joins the network. After selecting the best backbone node (BN) in Figure 1, the non-backbone node (NBN) requests the BN to join the network and starts its timer to save the packet. Figure 2 sends a `Packet-Join_Req` to a specific node, represented by `opt_BN[i]`. Upon reception, the node `N` handles two possible outcomes. If an "Accept" response is received, it sets a variable `NTnode` to true, indicating a successful communication. Conversely, if a "Denied" response is received, the code initiates a process to find an alternative node with superior energy efficiency. This involves iterating through available nodes and comparing their fitness values, excluding the initially selected node. The code updates variables such as `max_fitness` and `BN_index_tmp` to identify the most suitable alternative. Suppose no alternative node is found (indicated by `max_fitness` remaining zero) then in that case, the number of free nodes is set to zero, and the process restarts to attempt communication with the newly selected node. Overall, Figure 2 orchestrates a dynamic and adaptive communication strategy in the WSN, optimizing node selection based on energy efficiency and load balancing criteria [4]. The non-backbone node joining flowchart is shown in Figure 3.

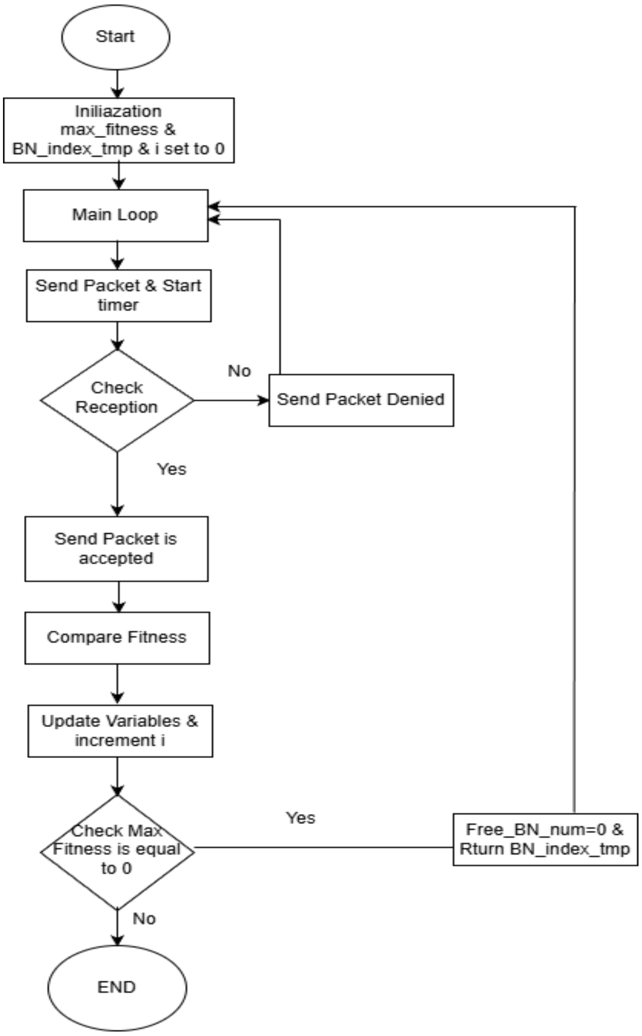

Figure 3. Non-backbone node joining flowchart

3.1.3 Reorganization of Backbone Node by Child Nodes

Figure 3 presents the residual energy of BN as itt focuses on energy efficiency and load balancing. It starts with initializing a timer, `energy-examine-time`, to a specific value. The subsequent loop checks if the timer has expired, and within each iteration, it examines the current energy level of the node. If the energy level drops below a certain threshold (`R%`), a sequence of actions is initiated to address the low energy condition. Upon detecting low energy, the node sends a "Pckt Del" signal to a designated backbone node (BN) and waits for an acknowledgment. If the acknowledgment is received, it indicates successful communication with the BN. The node then takes measures to optimize energy usage, such as removing itself as a child node, transforming into a non-backbone node, and deleting child nodes due to low energy. Subsequently, these child nodes are required to rejoin the network. If the acknowledgment is not received, the code continues to the next iteration without taking further action [6]. The reorganization of the backbone node by child nodes flowchart is shown in Figure 4.

The EBLBP proactively addresses nodes with low energy levels. By notifying the BN and taking appropriate actions, such as redistributing nodes and eliminating those with insufficient energy, Figure 3 helps to maintain a balanced energy distribution in the network. The decrementing of `energy_examine_time` within each iteration ensures that this examination process occurs within the specified timeframe. Thus, Figure 3 is crucial for extending the network lifespan and maintaining a reliable operation.

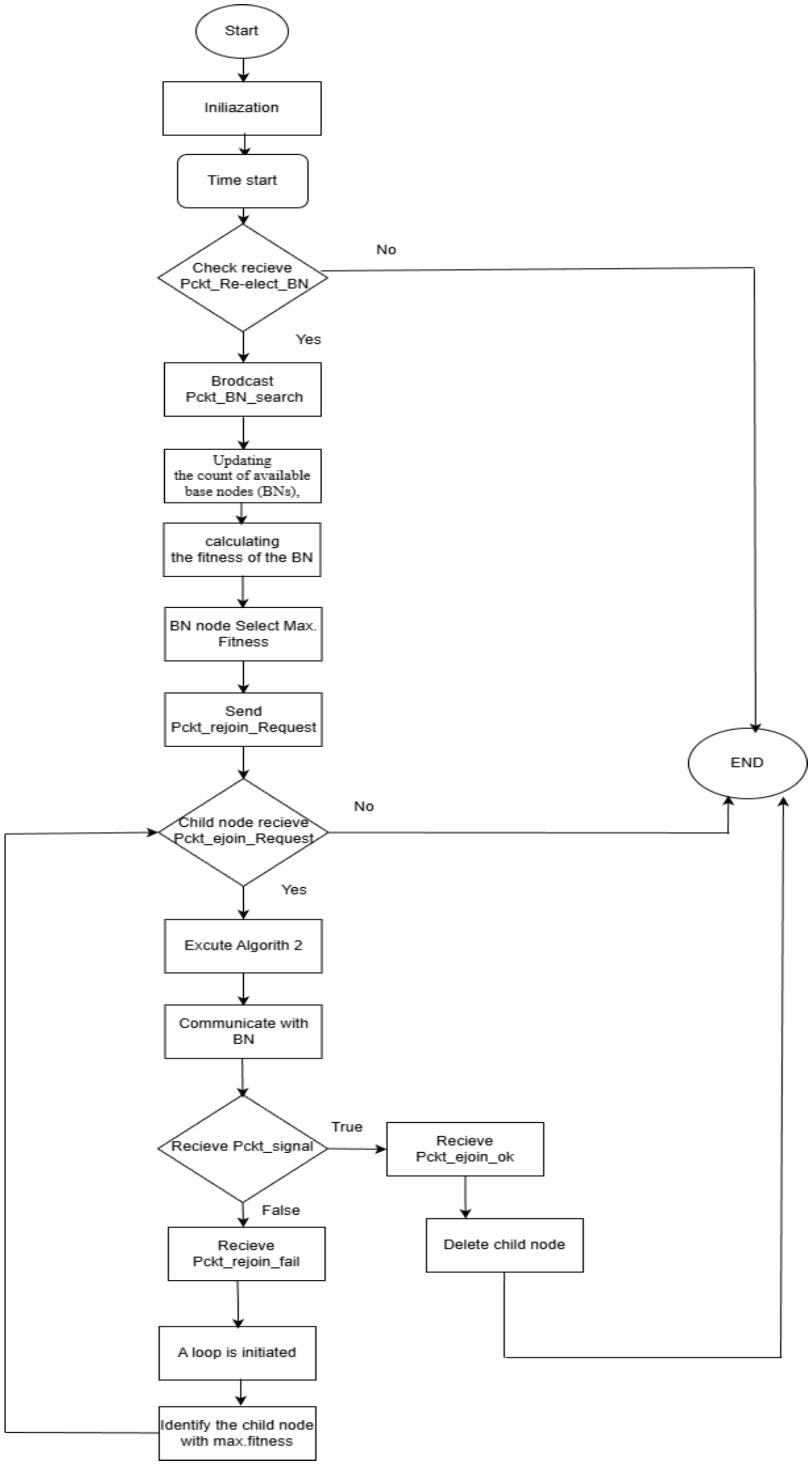

Figure 4. Reorganization of backbone node by child nodes flowchart

3.1.4 Managing the Re-election and Re-selection of nodes within the network

In the context of WSNs, where sensor nodes often contend with limited energy resources, the need for dynamic and intelligent load distribution becomes paramount. The EBLBP aims to address this challenge by orchestrating a series of operations, including the election of base nodes (BNs), the rejoining of child nodes, and the effective redistribution of computational tasks. By strategically selecting nodes based on their fitness, the EBLBP optimizes energy consumption and enhances the network's overall efficiency.

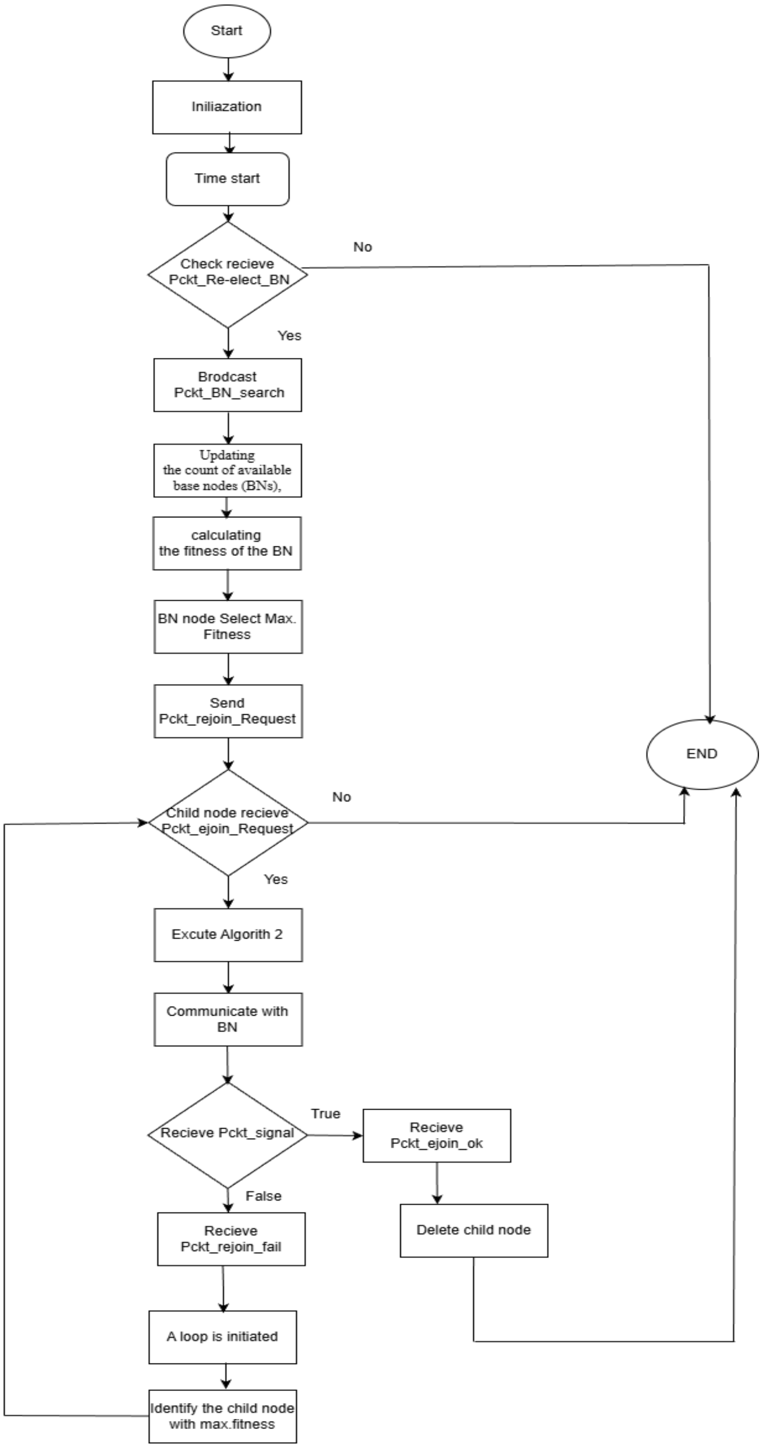

Figure 5. Re-electing of backbone node by child node flowchart

Initially, Figure 4 starts with clearing a set of child nodes and sending a "Pckt_Re_elect_BN" signal to each of them, coupled with a timer initiation. Subsequently, nodes respond to the "Pckt_Re-elect_BN" signal by updating the count of available base nodes (BNs), broadcasting a "Pckt_BN_search," and calculating the fitness of the BN. The BN then selects a child node with the maximum fitness and sends a "Pckt_rejoin_Request" to that child node. Upon receiving this request, the child node assesses its freedom to become a BN, executing Figure 2 accordingly, and communicates the result to the old BN through either a "Pckt_ejoin_ok" or "Pckt_rejoin_fail" signal. The BN processes these responses, deleting the corresponding child node if an "ejoin_ok" signal is received. However, in the case of a "Pckt_rejoin_fail" signal received by a sink node, a loop is initiated to identify the child node with the maximum fitness, prompting a "Pckt_ejoin_Request" to be sent to that child node, thus restarting the protocol. This protocol dynamically redistributes nodes within the WSN, prioritizing load balancing and energy efficiency, especially when nodes experience energy constraints [6]. Figure 5 shows the flow chart of Re-electing of the backbone node by the child node.

4. EXPERIMENTAL SETUP

NS2, or Network Simulator 2, is a widely utilized discrete event simulator for network research and development. NS2 is particularly well suited for simulating wireless communication networks since it provides a versatile environment for assessing various protocols' performance, scalability, and efficiency.

To implement the EBLBP Figure in NS2, we need to set up a network simulation environment. This is done by installing NS2 and then designing the network topology by specifying the node's positions and connections, paying special attention to the backbone nodes, defining the traffic patterns and sources, and implementing the load balancing protocol. We also set simulation parameters, such as simulation time, packet sizes, and others. We must also choose performance metrics like energy consumption and efficiency. We created various experimental scenarios to test the protocol under different conditions by varying the number of backbone nodes. We must run the simulation, collect data, and analyze the results using NS2 tools. Finally, we compare EBLBP performance with other existing protocols to assess its energy efficiency and load-balancing capabilities.

5. EBLBP IMPLEMENTATION, MEASURED RESULTS, AND DISCUSSION

EBLBP is considered as a hierarchical routing protocol for wireless sensor networks (WSNs) to optimize energy consumption and prolong the network lifetime. In EBLBP, nodes are organized into a backbone, forming a structured network with efficient communication paths. The protocol employs a proactive routing strategy, sending periodic updates to maintain the backbone structure. NS2 simulation of EBLBP has three functions: a self-organized tree-based network, a balanced energy consumption, and a reselecting sink node. The simulation parameters with which the initial network is formed are presented in Table 2,.

Table 2. Simulation parameters

Parameter	Value
Number of nodes	100 to 600
Communication radius	15m
Send packet power	0.66w
Receive packet power	0.40w
Sleep power	0.035w
Broadcast packet period	0.1s
Pckt_Join_Request period	0.5s
Initial energy	20J-29J
Maximum hop	10
Period for searching backbone node	0.2s
Period for checking balance energy	8s
Period for Pckt Del packet	0.3s
Number of iterations	4

5.1 XGRAPH Tool in NS2

Figure 6 shows a graph generated by the Xgraph tool in NS2 that compares the self-organized time of three different network protocols: EBLBP, AODV, and DSDV. Figure 6 compares the scalability and efficiency of different routing protocols in a network. EBLBP seems to have the best performance in terms of self-organized time. It can establish a tree-based network structure more quickly than the other two protocols, which is beneficial for balancing energy consumption and reselecting the sink node in a large-scale network.

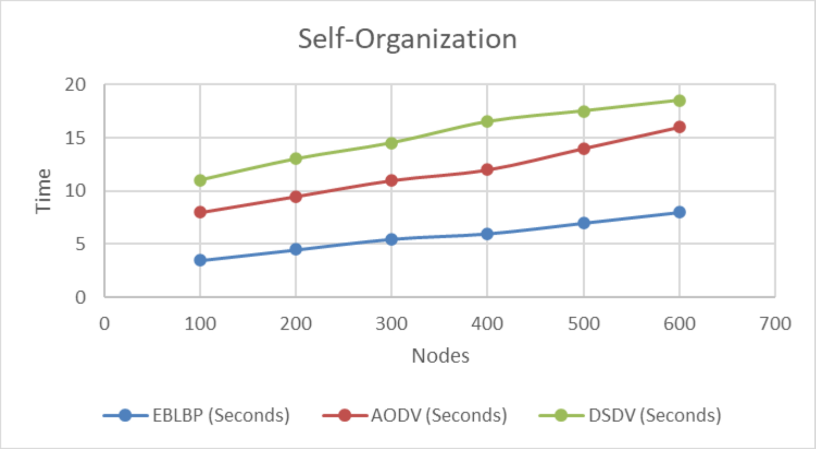

Figure 6. Self-organized time of EBLBP, AODV, and DSDV protocols

Table 3 provides a comparative view of the self-organized time required by the three different protocols: EBLBP, AODV, and DSDV. These times are measured in seconds and estimated based on the number of nodes in the network, ranging from 100 to 600 nodes. From the table, it is obvious that the EBLBP consistently performs better than AODV and DSDV, requiring less time to self-organize for the same number of nodes. AODV performs better than DSDV but takes more time than EBLBP. In the highest tested range (600 nodes), DSDV exceeds 18 seconds for self-organization, while EBLBP and AODV still manage to stay under 18 seconds. Thus, the table indicates that EBLBP is the most efficient protocol for self-organization in large networks.

Table 3. Self-organized time comparison

Number of Nodes	EBLBP (Seconds)	AODV (Seconds)	DSDV (Seconds)
100	3.5	8	11
200	4.5	9.5	13
300	5.5	11	14.5
400	6	12	16.5
500	7	14	17.5
600	8	16	18.5

Table 4. Protocols comparison

Protocols	Efficiency	Scalability
EBLBP	Fastest	Struggles with more nodes
DSDV	Slowest	Struggles with more nodes
AODV	Medium	Struggles with more nodes

Based on the data provided in Table 3, regardless of the number of nodes, EBLBP always takes the least time to self-organize. This makes it the most efficient Figure among the three. On the contrary, DSDV consistently takes the most time to self-organize, making it the least efficient among the three. The performance of AODV falls between EBLBP and DSDV. For all three Figures, as the number of nodes increases, the time for self-organization also increases. This suggests that all three Figures may struggle with scalability to some extent as represented in Table 4.

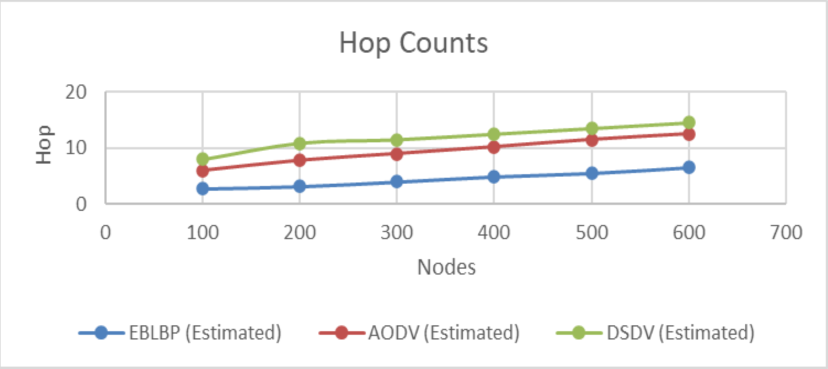

Figure 7. Average hop count of EBLBP, AODV, and DSDV protocols

Figure 7 illustrates the relationship between the number of nodes in the network and the average number of hops a data packet must traverse through the network for each protocol. Figure 7 and Table 5 show that EBLBP has a lower average hop count in comparison to AODV and DSDV. This is indicative of the strategy of EBLBP to form a tree-based network where data packets might traverse more nodes to reach the sink node, possibly to balance energy consumption and ensure sink node reselection. On the contrary, DSDV has the highest average hop count.

Table 5. Estimated average hop counts for different routing protocols

Number of Nodes	EBLBP (Estimated)	AODV (Estimated)	DSDV (Estimated)
100	2.8	6	8
200	3.2	7.8	10.9
300	4	9	11.5
400	4.9	10.2	12.5
500	5.5	11.5	13.5
600	6.5	12.5	14.5

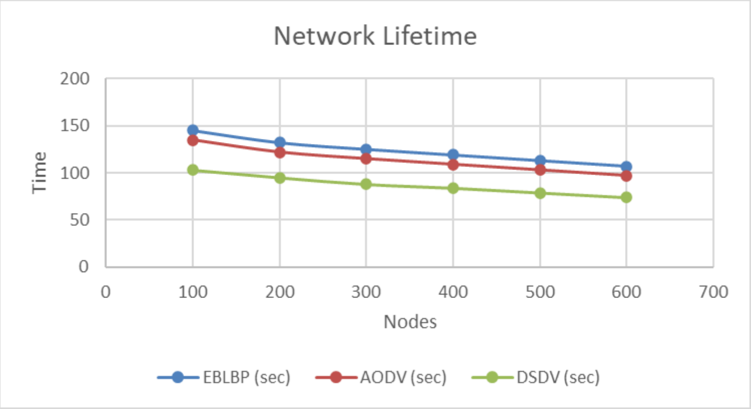

Figure 8. Network lifetime of EBLBP, AODV, and DSDV

The performance of AODV lies between the other two protocols, indicating that it may balance the number of hops with the need to find efficient routes on demand. Figure 7 gives a visual representation of how these protocols scale with an increasing number of nodes, with a particular focus on the hop count, which is a key factor in network performance, energy consumption, and overall efficiency, indicating that EBLBP is the most scalable of the three protocols.

Table 6. Comparison of network lifetimes for EBLBP, AODV, and DSDV protocols

Number of Nodes	**EBLBP (sec)**	**AODV (sec)**	**DSDV (sec)**
100	145	135	103
200	132	122	95
300	125	115	88
400	119	109	84
500	113	103	79
600	107	97	74

Table 6, shows a comparison of the lifetimes of the three protocols: EBLBP, AODV, and DSDV. The improvement in resource utilization and extension of network average lifetime are calculated by comparing the lifetimes at the highest number of nodes (600) to the lowest number (100). The calculation demonstrates that EBLBP has the smallest reduction in network lifetime at approximately 16.55%, which is the best improvement in resource utilization among the three protocols. For network lifetime the performance of EBLBP in comparison to AODV and DSDVcan be seen in the Figures 8 and 9. EBLBP has a higher network lifetime initially, indicating that its energy balancing and sink node reselection functions are effective at extending the operation time of the network before nodes start to fail due to energy depletion. However, as the number of nodes increases, the lifetime begins to decrease, suggesting that there may be scalability challenges with the EBLBP in very large networks.

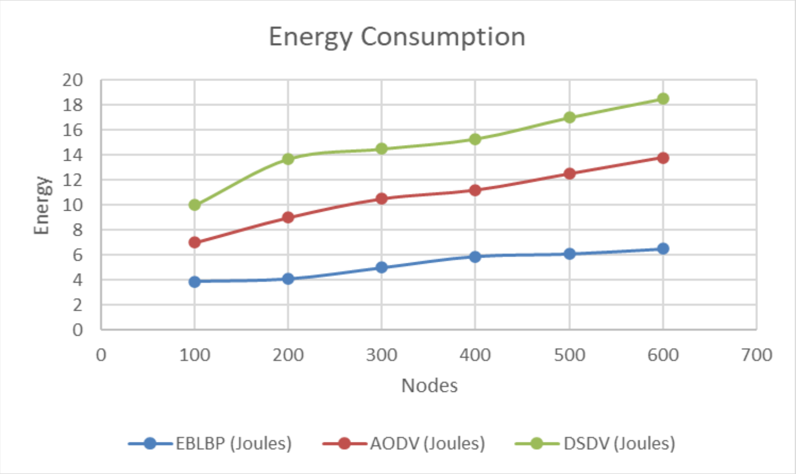

Figure 9. Energy consumption for EBLBP, AODV, and DSDV protocols

To determine the best energy efficiency among EBLBP, AODV, and DSDV, energy consumption is compared at the highest and lowest nodes, and the absolute reduction calculated for each protocol is 2.6, 6.8, and 8.5 Joules respectively._The percentage reduction for each protocol is calculated, resulting in 66.67%, 97.14%, and 85% increases. EBLBP is the best in energy consumption as the number of nodes goes from 100 to 600, as is clear from Figure 9, Table 7.

Table 7. Energy consumption by routing and nodes

Number of Nodes	EBLBP (Joules)	AODV (Joules)	DSDV (Joules)
100	3.9	7	10
200	4.1	9	13.7
300	5	10.5	14.5
400	5.9	11.2	15.3
500	6.1	12.5	17
600	6.5	13.8	18.5

6. THE COMPARISON BETWEEN THE ROUTING PROTOCOLS EBLBP, AODV, AND DSDV

Table 8, provides a comparative overview of EBLBP, AODV, and DSDV routing protocols in terms of their performance metrics, considering self-organized time, hop count, lifetime, and energy consumed. The protocol's suitability, however, depends on specific network requirements and characteristics.

Table 8. Comparison between the routing protocols EBLBP, AODV, and DSDV

Category	EBLBP	AODV	DSDV
Efficiency (self-organize Time)	Fastest (least time for self-organized)	Medium	Slowest (most time of self-organized)
Scalability (hop count)	Most scalable (lower average hop count)	Moderate	Low (highest hop count)
Network Lifetime	Prolonged due to Energy-Efficient Backbone	Moderate, Depends on Routing Efficiency	Prolonged with Proactive Route Updates
Energy Consumed	Optimized due to Backbone Efficiency	Moderate, Reactive Energy Usage	Moderate to High, Proactive Maintenance

7. CONCLUSIONS

Our numerical findings derived from the EBLBP investigation within WSNs underscore its substantial contributions to energy efficiency and load balancing. Through extensive simulations, the remarkable energy management of EBLBP, exemplified by an average consumption of 2.6 joules, emphasizes its efficiency in adapting to diverse node configurations. The protocol's standout achievement is a substantial 66.67% reduction in overall energy consumption from 100 to 600 nodes, solidifying its role as a frontrunner in optimizing resource utilization. Even with a gradual increase in self-organized time, peaking at almost 8 seconds for 600 nodes, EBLBP remains a positive force in enhancing network stability and performance. These compelling numerical results position EBLBP as a standout protocol, affirming its positive and impactful contribution to energy efficiency and overall effectiveness within WSNs.

In the future, to improve the Energy-Efficient Backbone Assisted Protocol (EBLBP) in wireless sensor networks (WSNs), We will focus on security considerations, including the integration of robust security mechanisms, such as encryption and authentication, to address potential threats to data integrity and confidentiality. We may also explore the real-world deployments and energy harvesting integration which will validate and extend the protocol's applicability under diverse scenarios and promote sustainability.

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