Energy-Efficient Dynamic Cluster Formation for WSN Lifetime Optimization

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Abstract

Wireless sensor networks (WSNs) have become increasingly popular over the last few decades, particularly in environmental monitoring, industrial control, healthcare, security, and offer the possibility of collecting data on physical and environmental phenomena, enabling advances in safety and intelligent surveillance. Each sensor node, equipped with physical sensors, processing circuitry, and wireless communication modules, acts as an autonomous agent capable of monitoring its surroundings and relaying information. However, large-scale deployment of these networks introduces challenges such as efficient energy management, communication reliability, fault tolerance, data security, and dynamic topology management. This article addresses these challenges and proposes innovative solutions to enhance WSN performance and sustainability, focusing on optimizing routing protocols. We propose a new solution to optimizing the AOMDV routing protocol, aiming to improve Quality of Service (QoS) while optimizing energy efficiency and the network lifetime. Additionally, we introduce a new clustering algorithm that dynamically forms clusters based on node density and energy levels to minimize communication overhead and prolong network lifetime. Extensive simulations using the NS2 network simulator demonstrate the effectiveness of our methods in improving QoS, energy efficiency, and network lifetime compared to existing protocols. Our contributions offer promising solutions for enhancing WSN performance and sustainability, enabling broader adoption in diverse applications.

Key Words:WSN; AOMDV; QoS; NS2; Lifetime.

1 Introduction

Wireless sensor networks (WSN) are generally made up of small sensors distributed in a more or less random geographical area known as the catchment area or area of interest. These networks (1) allow data to be collected on physical and environmental phenomena, paving the way for numerous innovations. WSNs are distinguished by their ability to collect, process and transmit data autonomously and collaboratively. Each sensor node (2) equipped with physical sensors, processing circuitry, and wireless communication modules acts as an autonomous agent monitoring its environment and transmitting information to other nodes or a central base station. However, their massive deployment presents technical and engineering challenges, including efficient energy management, communications reliability, fault tolerance, data security, and dynamic topology management.

Routing (3; 5) in such networks is pivotal in ensuring efficient data delivery while optimizing energy consumption and network lifetime. In WSNs, traditional routing techniques encounter difficulties like dynamic network topologies, high energy consumption, and constrained bandwidth. The ability of the Ad hoc On-Demand Multipath Distance Vector (AOMDV) protocol to create several routes between a source and a destination has made it stand out among these protocols.However, we have turned our attention to clustering techniques for further efficiency gains.

Clustering (7) involves organizing sensor nodes into groups or clusters. Where there may be a designated cluster head for each cluster who is in charge of arranging communication both inside and between clusters. The integration of clustering with routing protocols such as AOMDV presents a promising avenue to address the unique challenges of WSNs. By leveraging clustering, network resources can be allocated more efficiently, reducing overhead and prolonging network lifetime. Additionally, clustering facilitates localized data processing and aggregation, mitigating the impact of bandwidth constraints, and enhancing scalability. The present article discusses the synergy between clustering and the AOMDV protocol in WSNs. We explore how clustering enhances AOMDV performance by reducing routing overhead, improving network scalability, and increasing resilience to node failures.

In this article, we explore these challenges and propose innovative solutions to improve the performance and sustainability of WSNs. In particular, we focus on optimizing routing protocols, which are crucial for efficient communication

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in these networks, often deployed in hostile environments. This Introduction lays the foundations of our research. Section 2 analyses the AOMDV routing protocol and the principle of clustering routing protocols in detail. Section 3 presents related work, while Section 4 describes the implementation and simulation of our clustering algorithm under NS2, demonstrating its energy efficiency and communication reliability improvements. In summary, this work aims to significantly improve routing in WSNs by optimizing routing protocols and implementing innovative solutions to these networks' technical and engineering challenges..

2 AOMDV protocol and clustering techniques

2.1 The AOMDV Routing Protocol

Adhoc On Demand Multipath Distance Vector or AOMDV (3) is a multipath reactive routing protocol. Route maintenance and route discovery are its two primary stages. This multipath routing protocol establishes several disjoint routes without routing loops from source to destination. However, it mainly uses the best path in terms of hop count to transfer data. These multiple paths can be used for load balancing or to provide backup routes in the event of failure of the main route being failed. AOMDV 's (4) primary concept is to compute various routes from the traffic source to the destination while avoiding the formation of routing loops. At the start of the procedure, the source sends the route request message RREQ (Route REQuest) to its adjacent nodes. The adjacent nodes receive the RREQ and send an RREQ to their adjacent nodes. This process continues until the destination node receives the route request (see Figure 1).

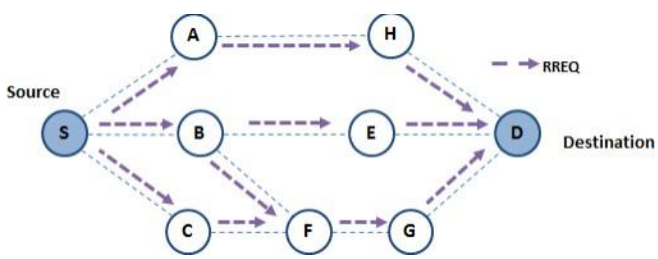

Figure 1: Route Discovery Phase .

The destination (5) node generates an RREP (Route REPly) for each RREQ received. The source node receives several RREPs corresponding to the paths discovered. If only one RREP is received, i.e., only one route is recognized between the source and the destination, then it sends the data packets on this route. Otherwise, if several RREPs (6) have been received, the source chooses the best route, i.e. the one with the lowest hop count. The other routes await the arrival of a RERR packet indicating that the main route has been broken. In this case, the best route among the alternative routes is selected to retransmit the data. If no RREP is received, a new route discovery phase is triggered (see Figure 2)

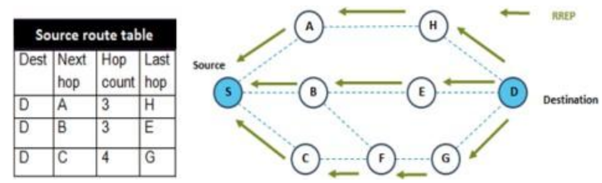

Figure 2: RERP packet generation

2.2 Clusterig technique in WSNs

The Clustering (7) in networks is a distributed method of dealing with problems such as network lifetime and energy. These problems can be solved by clustering sensor nodes. A cluster head (CH) controls internal communication between sensors in the same cluster. Cluster heads can communicate with each other to reach the sink.

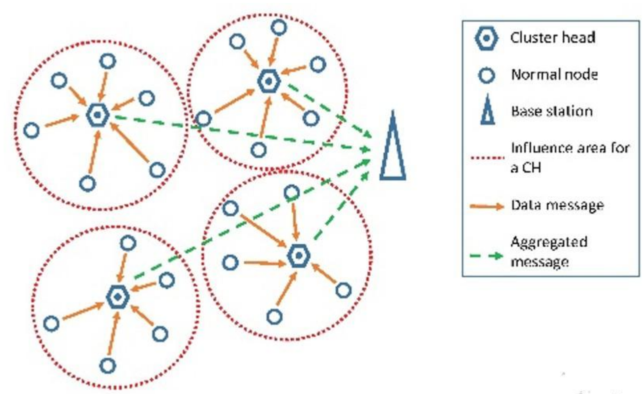

Figure 3: Clustering procedure in a wireless sensor network.

As we can see in Figure 3 are some important components, listed as follows:

- Cluster member (normal node);
- Cluster head;
- Gateway node.

In the wireless network (8), each cluster has a group leader, known as the cluster head (CH), who manages inter-cluster and intra-cluster communication. One of the main metrics of WSNs is the election of cluster heads:

1. large residual energy;
2. large number of neighbors;
3. The distance of nodes from the base station.

Cluster leader nodes (7) link sensor nodes and the base station. The cluster technique in Wireless Sensor Networks (WSNs) offers several advantages, it facilitates data aggregation, which helps reduce data transmission and conserve energy. Additionally, it enhances resource reusability and enables the formation of a virtual backbone for inter-cluster routing through cluster heads and gateway nodes. The cluster (8) structure contributes to a smaller and more stable network, ultimately improving network lifetime and minimizing network traffic. Furthermore, it supports data aggregation and updates at cluster heads while reducing channel contention.

Various clustering (9) routing protocols ely mostly on CH selection schemes . CH selection methods include deterministic, random, and adaptive approaches. Deterministic schemes position CHs at fixed network locations, while random schemes select CHs randomly from sensor nodes. Adaptive schemes base CH selection on location or battery .Clustering mechanisms (8) can be static or dynamic. Static clustering maintains a fixed topology throughout the network's lifetime, leading to quick battery depletion in CHs. Dynamic clustering allows topology changes over time, promoting energy balance across sensor nodes and extending network lifetime.

3 Related Work

Multipath routing protocols (10) rely on multiple paths for packet transmission. One of the best multipath protocols is AOMDV. Although the AOMDV protocol has many advantages, maintaining multiple alternative paths can reduce the battery life of nodes, and may generate more control packets such as error, hold and link discovery messages. We begin with a state-of-the-art review of existing work in the literature.

The authors in (11) sought to balance the battery use of mobile nodes and extend the network lifetime. A new routing protocol called EA-AOMDV is presented.The EA-AOMDV protocol's primary goal is to balance nodal energy consumption to keep one or more crucial nodes from running out of energy and ceasing to be able to communicate with the rest of the network.During the path selection phase, the protocol searches for each route's average residual energy and least nodal energy. The sum of the average and minimum energy is the parameter used to choose the best routes. The outcomes demonstrate enhanced network lifetime, overload, end-to-end latency, and packet delivery ratio performance.

In (12) the authors propose a multi-path reactive routing protocol to save network energy and bandwidth. The optimal routes regarding available bandwidth and the least amount of leftover energy form the basis of the suggested routing protocol. This protocol is incredibly efficient, using less energy and losing fewer packets. However, the battery of nodes on these channels might quickly run out if you constantly rely on the same paths with high bandwidth and low energy.

The authors of (13) , used an optimization algorithm known as particle swarm optimization (PSO) to suggest an AOMDV routing protocol optimized for energy consumption. To cut down on consumption, the system determines the route with the best distance. The energy level is highest on the chosen main path. Upon receiving a route response packet, an intermediate node first determines how much energy is left and adds it to the energy field of the response packet. The sender will select the path with the greatest average energy value if it receives several responses. Simulation results indicate better communication throughput, latency, and node lifetime performance.

In (14), The authors suggest utilizing the multipath routing protocol AOMDV to increase network longevity and energy efficiency. The proposed AOMDV EE protocol uses energy thresholds to choose energy-efficient routes from those available during protocol implementation. The results show that the suggested EE AOMDV protocol is more energy-efficient than the AOMDV protocol. The analysis utilizes network lifetime and energy usage by changing node speed.

A multipath routing technique is suggested by the authors in (15). When generating numerous disjoint pathways, the proposed protocol, known as AOMDV-FF, considers the distance between the source and the destination and the residual energy of nodes. According to simulation results, AOMDV-FF has superior throughput and overhead.

The LEACH protocol is improved by LEACH-VD (22).to lower energy usage. Three steps make up the protocol's operation. The initial stage is to create clusters and choose cluster heads using the LEACH protocol. The shortest routes between each cluster head are then identified. Lastly, the shortest pathways are found using the DIJKSTRA algorithm. The energy consumption of the DIJKSTRA algorithm, which determines the shortest pathways, is one of LEACH-VD's primary disadvantages.

TEEN-V (23).enhances the TEEN protocol to reduce data transmission rates. It works in two stages: firstly, running the TEEN protocol to establish clusters and designate cluster leaders, and secondly, calculating the shortest paths between cluster leaders to save energy. However, a notable drawback of TEEN-V is the energy consumption associated with the vector quantization process.

The authors of (25) uses Dijkstra's algorithm to optimize energy in WSNs. Dijkstra's algorithm is adapted to minimize energy consumption by selecting routes that balance the energy load between nodes. This work focuses on how graph-based algorithms can improve energy utilization in WSNs, providing a promising approach for long-lived, sustainable sensor network deployments.

4 The proposed protocol

There are several particular difficulties in creating an effective routing system for wireless sensor networks (WSNs)(16). Power management is one of the main problems. In a WSN, routing is essential, enabling individual nodes to transmit data captured from sources to destinations via intermediate nodes. Each transmission consumes energy, from data or as a relay for other nodes. Consequently, a routing algorithm must incorporate energy management mechanisms to minimize node consumption and extend the network lifetime.Furthermore, an effective routing system needs to consider the unique properties of sensors, such as energy resource limitations and hardware constraints. developing routing strategies that adapt to these constraints is crucial to meet application requirements and optimize network performance.

This section describes the simulation and implementation of our clustering algorithm in WSNs using NS2. We explain the steps and tools adopted to implement and evaluate our approach, which aims to optimize energy consumption and increase network lifetime. In our solution, proposed Sensor networks comprise sensors. During simulations, sensors rapidly exhaust energy. Sensors are randomly distributed over a 1000 m x 1000 m area. The base station is situated at the central location of the network. The network's sensors are also uniform. Moreover, the sensors have a data to send to the base station using a communication file with a simple energy model. The protocol consists of two main stages(see Figure 4): configuration and communication.

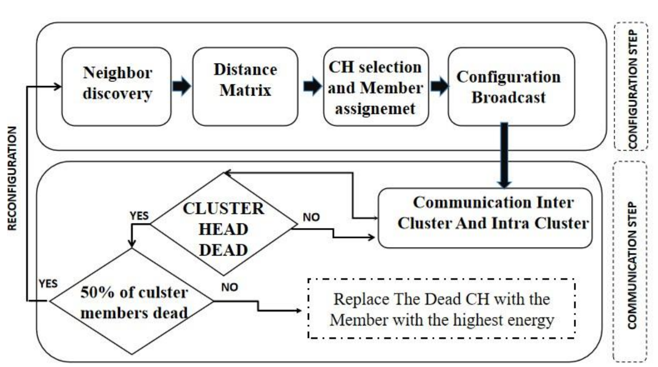

Figure 4: Proposed protocol architecture

Enhancing energy conservation, a crucial factor in prolonging the life of a sensor network, is the goal of our solution. Clusters are formed and their cluster leaders are chosen using a hybrid approach. formation of clusters using a novel centralized algorithm. Based on the distances between sensors and a predetermined threshold, our algorithm clusters the closest sensors.

There are two primary steps in our algorithm:
- A centralized network configuration stage, which is repeated multiple times over the network's lifetime.
- A distributed communication step between the base station and the network sensors.

In the first stage, the BS divides the network into clusters using the Euclidean distance between sensors. This division is based on an adaptive and dynamic algorithm, enabling efficient allocation of network resources.The second stage, communication, establishes communications between the network's sensors and the base station, based on the clusters formed in the first stage. This hybrid approach aims to optimize energy utilization while ensuring efficient network coverage by all nodes. In the following sections, we will detail each step of the algorithm and explain in detail how it works.

4.1 Configuration stage

The configuration stage is carried out in offline mode before communication.. In this stage, the base station divides the network into several clusters according to 4 phases: from neighbor detection to the assignment of member nodes to their group leader (CH).

4.1.1 Neighbor discovery phase

In this phase, nodes broadcast a HELLO message to discover adjacent nodes in a single hop. The result of this phase is to generate an adjacency table for each node. The aim of this step is to generate the 1-hop neighbors from which the RREQ packet will be broadcast. Once all nodes generate their neighbor table the configuration step starts to generate the cluster heads.

4.1.2 Distance matrix creation phase

In this phase, the base station creates a distance matrix between nodes based on Euclidean distance. We can represent the Euclidean distance matrix D as an $m \times m$ matrix where the element D_{ij} represents the distance between node i and node j. Thus :

$$D = \begin{pmatrix} d(\mathbf{p}_1, \mathbf{p}_1) & d(\mathbf{p}_1, \mathbf{p}_2) & \cdots & d(\mathbf{p}_1, \mathbf{p}_m) \\ d(\mathbf{p}_2, \mathbf{p}_1) & d(\mathbf{p}_2, \mathbf{p}_2) & \cdots & d(\mathbf{p}_2, \mathbf{p}_m) \\ \vdots & \vdots & \ddots & \vdots \\ d(\mathbf{p}_m, \mathbf{p}_1) & d(\mathbf{p}_m, \mathbf{p}_2) & \cdots & d(\mathbf{p}_m, \mathbf{p}_m) \end{pmatrix}$$

where each element of the matrix is calculated as follows :

$$D_{ij} = d(\mathbf{p}_i, \mathbf{p}_j) = \sqrt{\sum_{k=1}^{n} (p_{ik} - p_{jk})^2}$$

4.1.3 CH selection and Member assignemet

In this phase, the base station selects the group leaders based on the distance matrix and the distance threshold K according to our CH selection algorithm.The distance threshold K is a value used to determine whether a node can be selected as a group leader. This value represents the minimum distance between two clusters, and our algorithm generates a list of cluster heads whose distance between each two cluster heads must exceed or equal the value of K.

The following algorithm represents the CH selection technique

Algorithm 1 Node clustering

Determine the distance matrix's maximum value.
Store the distance matrix's greatest value's indices i and j.
Initialize CHlist with i and j *{*First cluster heads*}*
for Each node in the network **do**
  boolean isClusterHead ← **true**
  for each cluster head in CH **do**
    if distance between node and cluster head ≤ K **then**
      isClusterHead ← **false**
      break
    end if
  end for
  if isClusterHead **then**
    Add node to CH list as new cluster head
  end if
end for
for each node from 0 to n **do**
  Find the nearest head cluster using the distance matrix
  Assign element to clustet head
end for

Now that we have all the CHs, nodes will be assigned to their nearest cluster based on Euclidean distance. A configuration message containing the node identification and its cluster will be sent.

4.1.4 Configuration Broadcast phase

The broadcasting of a configuration message with the sensors' identity completes the configuration process. Each sensor only keeps the data it needs due to issues with sensor memory limitations. Each sensor retains only the data pertaining to the cluster in which it is situated. The cluster head keeps the list of nearby cluster heads. During the communication step, each cluster head takes charge of communication between the clusters.

4.2 Communication stage

Two layers of communication exist in a WSN: inter-cluster communication between cluster heads and the base station and intra-cluster communication between clustrer members and cluster leaders. At this point, nodes in a cluster exchange information with their cluster leader to send data to the base station. The cluster manager (CH) manages communication between the clusters and relays data between them every time period. The base station re-evaluates sensor status, such as power consumption. If the CH is destroyed, we call this a reconfiguration phase.Algorithm 2 presents the reconfiguration technique

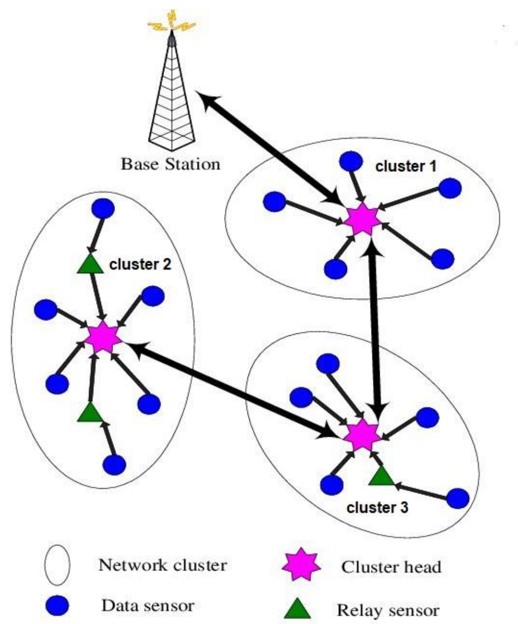

Figure 5: Clustered communication architecture for a sensor network

Algorithm 2 Cluster reconfiguration

TH = Threshold for rejected clusters (minuscules) 5%
X = Percentage of living cluster members
for each CH in CHlist **do**
  if $Energy_{CH} \leq TH$ & $X \geq 50\%$ **then**
    Identify the node with the highest energy.
    Designate this node as the new cluster leader.
    Update cluster assignments accordingly.
  end if
  if $Energy_{CH} \leq TH$ & $X \leq 50\%$ **then**
    Eiminating dead nodes
    Repeat configuration phase
  end if
end for

This procedure identifies the node with the highest energy within the low-energy CH cluster and designates it as the new cluster leader. It then updates the cluster assignments accordingly.

5 Results and Interpretation

This section presents the results of simulations performed on the AOMDV protocol without our approach, and with our approach on WSNs. We begin by defining the various simulation parameters, followed by an interpretation and discussion of the results obtained.

5.1 Simulation parameters

Wireless sensor networks count 140 sensors. The sensors are randomly distributed over 1000 × 1000 meters, with the base station in the center. All sensors are homogeneous, monitoring the environment and continuously sending data to the base station. Data processing power is neglected, excepte for data aggregation at thecluster-head level. The simulation environment is NS2.35. The AOMDV routing protocol uses four main functions: recvReq, recvRep, sendReq, and sendRep. It should be noted that the sendReq function consumes twice as much energy as the other functions. Simulations were carried out in the NS2 simulator. They were run on a test set comprising a sample of 140 randomly generated sensors. The basic parameters of the simulations are shown in the following table:

Parameters	Value
Catchment area	1000 × 1000
BS Position	500 × 500
Number of sensors	140
Number of communication	30
Packet size	512 bits
simulation time	180s
Threshold K	150, 200, 250, 300
Pause Time s	30, 90,120, 180
Initial energy	2500 (μJ)
Threshold for rejected clusters	5%
E_elec	50 nJ/bit
E_amp	1 pJ/bit/m^2
RREQ size	240 bits
RREP size	240 bits
SEND_REQ size	400 bits
END_REP size	400 bits
Collecting radius	20.0 m

Table 1: simulation parameters

5.2 Network performance

Metrics are routing protocol test parameters that allow us to measure the performance of a routing protocol, from which comparisons between protocols can be made. In our study, we considered the following metrics:

5.2.1 Packet delivery ratio

This parameter (17) represents the percentage of packets delivered to their destinations in relation to the number of packets sent into the network.

5.2.2 Average data packet latency

This is the average time required successfully deliver data packets from source to destination, including latency in including latency in queues, buffer storage time (18)

5.2.3 Dropped packets

This is the number of packets ignored or dropped by the CSF (18) .

5.2.4 The network lifetime :

is defined (19) as the time elapsed until all cluster heads (CH) have died. If tdeath CH is the death time of the last cluster leader, then the network lifetime Tli f e is given by:

$$T_{life} = t_{death\_CH}$$

where t_{death_CH} is measured in seconds (s).

5.2.5 Energy consumption

In the AOMDV protocol used WSNs, the energy consumption for different operations such as route request (RREQ), route response (RREP), request sending and response sending can be estimated as a function of various factors such as the energy consumption characteristics of sensor nodes and the length of messages sent (20).

To provide a detailed response, we need to consider :

1. Energy model:Commonly used models include the first-order radio model and the two-beam ground model. For simplicity, let's assume the first-order radio model first-order(21);
2. Message size:The size of RREQ, RREP and data messages (send request/send response) in bytes.;
3. Transmission and reception energy: Transmission energy (E_{tx}) and reception energy (E_{rx}) can be calculated using the following formulas (21):

$$E_{tx}(k, d) = E_{elec} \times k + E_{amp} \times k \times d^2$$

$$E_{rx}(k) = E_{elec} \times k$$

where E_{elec} is the power consumption per bit to operate the transmitter or receiver circuit, E_{amp} is the power consumption per bit per square meter for the transmission amplifier, k is the message size in bits, and d is the distance between transmitter and receiver (pickup radius) .

4. Route request (RREQ)
   Transmission energy for RREQ ($E_{tx,RREQ}$) :

$$E_{tx,RREQ} = E_{elec} \times k + E_{amp} \times k \times d^2$$

   Receiving energy for RREQ ($E_{rx,RREQ}$) :

$$E_{rx,RREQ} = E_{elec} \times k$$

5. Route response (RREP)
   Transmission energy for RREP ($E_{tx,RREP}$) :

$$E_{tx,RREP} = E_{elec} \times k + E_{amp} \times k \times d^2$$

   Receiving energy for RREP ($E_{rx,RREP}$) :

$$E_{rx,RREP} = E_{elec} \times k$$

6. Send request (SENDREQ)
   Transmission energy for SENDREQ ($E_{tx,SENDREQ}$) :

$$E_{tx,SENDREQ} = E_{elec} \times k + E_{amp} \times k \times d^2$$

   Receiving energy for SENDREQ ($E_{rx,SENDREQ}$) :

$$E_{rx,SENDREQ} = E_{elec} \times k$$

7. Sending response (SENDREP)
   Transmission energy for SENDREP ($E_{tx,SENDREP}$) :

$$E_{tx,SENDREP} = E_{elec} \times k + E_{amp} \times k \times d^2$$

   Receiving energy for SENDREP ($E_{rx,SENDREP}$) :

$$E_{rx,SENDREP} = E_{elec} \times k$$

These formulas are used to calculate the energy consumption for transmission and reception operations in the AOMDV protocol, taking into account message size and transmission distance.

5.3 Influence of distance threshold (K)

In this section, we examine the impact of distance thresholds on several key metrics in wireless sensor networks. The distance threshold is crucial in many clustering and routing protocols, determining the communication range between nodes and clusters formed. We focus in particular on its influence on energy and sensor lifetime, and on performance metrics such as Packet Delivery Ratio, number of lost packets, and delay in data transmission. Understanding how the choice of distance threshold affects these metrics is essential for designing sensor networks and optimizing their performance in various application scenarios. We explore these relationships empirically through simulation experiments, offering valuable insights for optimizing wireless sensor networks.

5.3.1 Influence of (K) on Formed Clusters

One of the crucial aspects of wireless sensor network optimization is how the distance threshold (K) influences cluster formation. Indeed, K plays a decisive role in the delimitation of clusters and how sensors group according to their spatial proximity. When K is higher, this implies that the communication range between nodes is greater, which can lead to larger clusters and a reduction in the total number of clusters formed. On the other hand, a lower distance threshold will favor the formation of smaller and more numerous clusters, as only nodes that are very close to each other will be grouped together in the same cluster. Thus, understanding the impact of K on cluster formation is essential for designing network architectures tailored to specific application requirements, and for maximizing communication efficiency and energy management in wireless sensor networks. From the graph, we can see that as the threshold decreases, the umber of clusters formed increases. Next, we'll examine how the threshold can influence energy and other metrics(see figure 6)

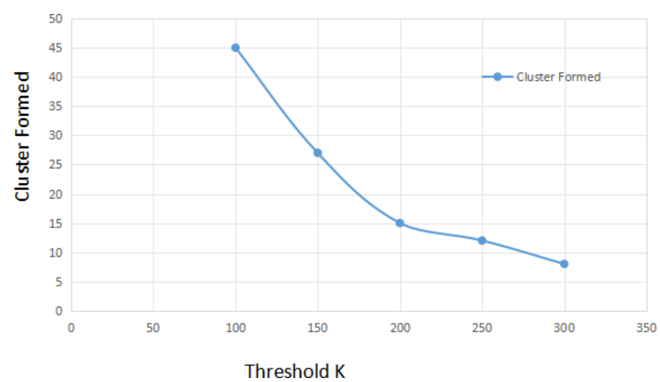

Figure 6: Influence of (K) on Formed Clusters

From the graph, we can see that as the threshold decreases, the number of clusters formed increases. Figures 7, 8 and 9 show clustered data with cluster heads and connections with K=100, 200 and 300, respectively.
Next, we'll look at how the threshold can influence energy and other metrics.

5.3.2 Influence of (K) on the metrics

- Energy consumed : we'll examine how the parameter K influences the energy consumed by the sensors over a 90- second period, as illustrated in figure 10,When K is reduced, more clusters are added, resulting in higher energy consumption. This is because more communication occure between the nodes, requiring higher energy consumption. We note that our approach has improved, as there is a big difference between using clustering and not. In particular, the total energy consumed

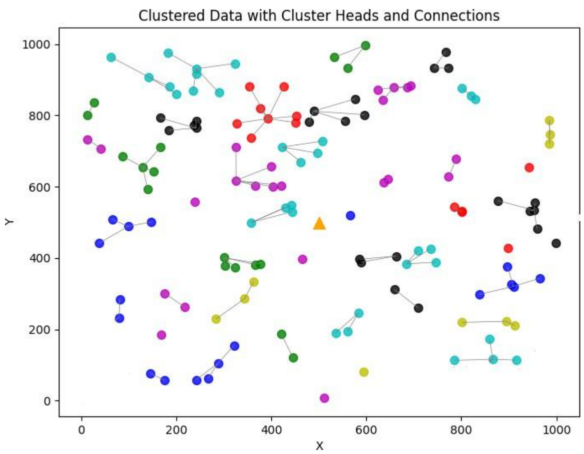

Figure 7: clustering with k = 100

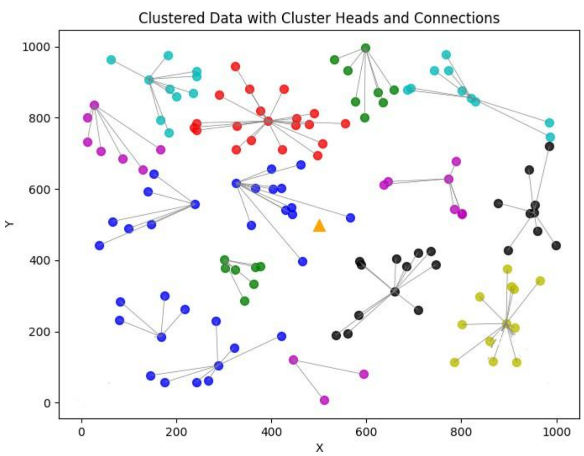

Figure 8: clustering with k = 200

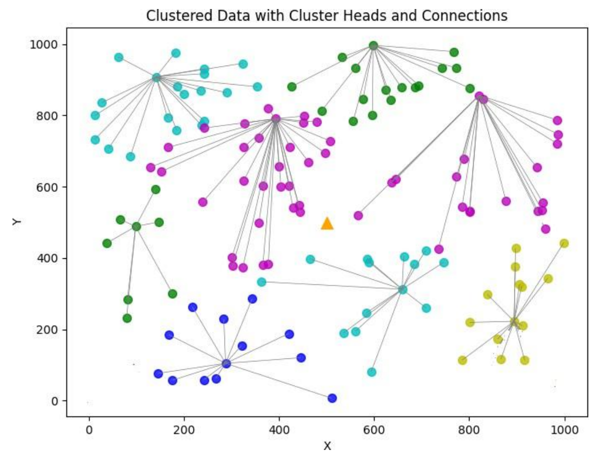

Figure 9: clustering with k = 300

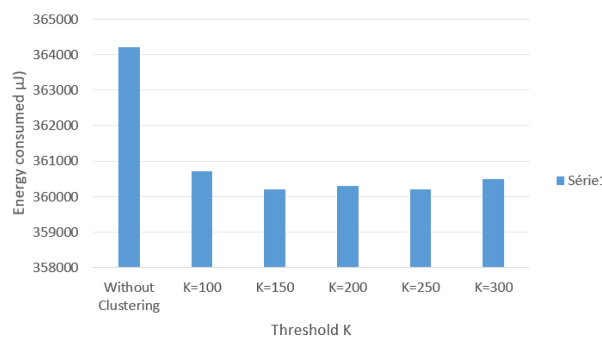

Figure 10: Energy consumed at time 90 seconds per threshold

by the sensors is significantly affected by the variation in K.

- PDR and Dropped packets:This section will examine how the threshold influences packet delivery rate (PDR) and packet loss. PDR is a key measure of network performance, representing the percentage of correctly received packets relative to the total number of packets sent (see figure 11,12)

  As we can see, the importance of the threshold parameter, noted k, in the quality of our network is undeniable. Indeed, an increase in k leads to an increase in the number of clusters formed, which intensifies communication between nodes and can influence the number of packets dropped. To illustrate this point, let's consider the following three cases:

  – For k = 300, we observe 4499 dropped packets.;
  – For k = 150, this number rises to 5208 dropped packets;

  It's therefore clear that DROPED150 ¿ DROPED300, which corresponds to 300 ¿ 150. However, the Packet Delivery Ratio (PDR) can also vary as a function of k. For example, AOMDV without clustering, the PDR is 43%, while with a threshold of k = 150, it can increase to 49%. This underlines the crucial importance of choosing our threshold wisely to optimize network quality, as measured by PDR. An inappropriate threshold can degrade network performance by affecting latency, reliability and overall communication efficiency. Therefore, it is crucial to carry out in-depth analysis and rigorous testing to determine the optimum threshold that will guarantee a perfect balance between the number of clusters and the communication load, thus maximizing the performance and quality of our network.

- delay: In figure 13 , We observed that the addition of our contribution increased the delay. For example, when we take the delay for k = 150, it is 8.7ms, whereas without clustering, it is 3.8ms. These two values are not significantly different. This relates to the fact that sometimes the packets from a node are very far from the

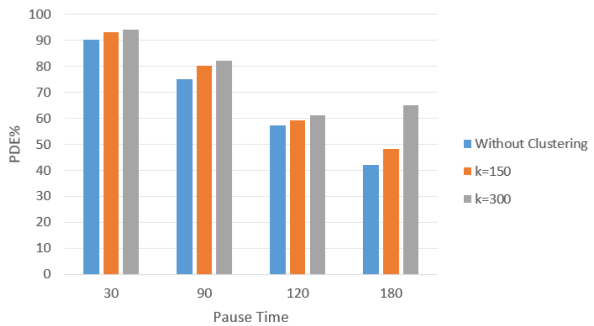

Figure 11: PDR versus pause time

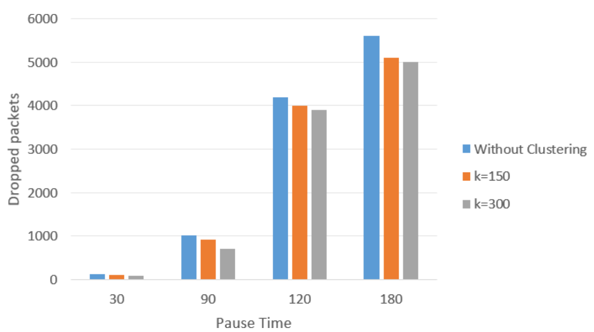

Figure 12: Ignored or dropped packets versus pause time

base station. As the AOMDV algorithm uses the shortest distance without clustering, we notice that packets are delivered quickly, but energy is not considered. However, in our approach, delivery may take a little longer, but with lower energy consumption. It is, therefore, essential to note that the threshold impacts the lead time. A judicious choice of threshold can help balance delay and energy consumption, thus optimizing our network performance.

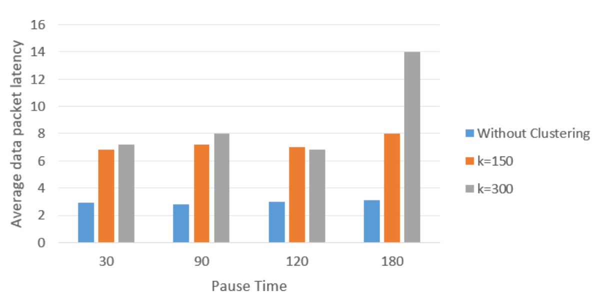

Figure 13: End to End delay versus pause time

5.4 Comparison between Our Approach and AOMDV:

we'll look at how our approach improved total sensor energy consumption and network lifetime. Optimizing the energy consumed by the sensors is a critical criterion for extending the lifetime of the sensors. For this comparison, we are interested in energy consumption per second throughout the 180-second simulation.

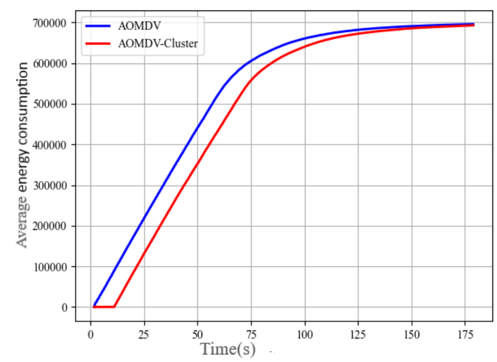

Figure 14: AOMDV VS AOMDV-cluster k = 250

From the figure 14, it's clear that the power consumption of the standard AOMDV quickly reaches a high level. In contrast, our approach shows a more moderate energy consumption and a slower increase. This demonstrates that our method is more efficient in terms of energy management, thus extending the life of the sensors. As a result, it is clear that our approach has improved the total energy consumption of the sensors, automatically leading to an increase in network

The notion of a wireless sensor network's lifetime has several definitions, In our study, we have chosen to define network lifetime in terms of the number of dead sensors at the end of the simulation. Figure 15 illustrates our approach compared with the normal AOMDV protocol, showing the number of dead sensors as a function of time (in seconds).

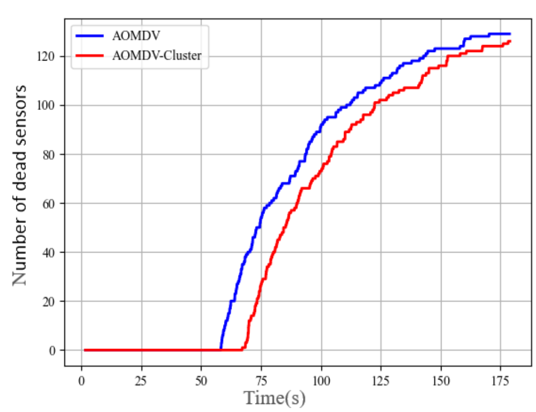

Figure 15: Comparison of the number of dead sensors between our optimized approach and the normal AOMDV protocol as a function of time.

5.5 Comparison with the MCL-BCRP approach:

In this section, we examine a comparison between our approach and that presented in (24). The latter uses the MCL-BCRP (Markov Cluster algorithm - Base Station Controlled Relay Protocol) algorithm for cluster formation, combining the MCL algorithm for this task with a new strategy for selecting sensor nodes acting as Cluster-Heads (CH), based on their location and residual energy level. In addition, the study in (24) compares the MCL-BCRP protocol with several other protocols commonly used for Wireless Sensor Networks (WSNs), including LEACH, TEEN and PEGASIS.

5.5.1 Comparison metrics

In this comparative analysis, we considered the following metrics:

- The number of clusters formed.
- The number of dead clusters at the end of the simulation.

This approach enables us to better assess the performance of our proposal by comparing it with that of an existing protocol such as MCL-BCRP, using objective and meaningful metrics for wireless sensor networks.

5.5.2 Simulation parameters

For this comparison, the simulation parameters used are as follows:

Parameters	**Value**
Catchment area	1000 × 1000
BS position	500 × 500
Number of sensors	100
Initial energy	$0.5J$
Threshold K	100
Radius of capture	20
Electrical energy(E_{elec})	50×10^{-8} J/bit
Amplification energy(E_{amp})	1.3×10^{-12} J/bit/m^2

Table 2: Simulation parameters

5.5.3 Results obtained

We obtained the following results for our approach (AOMDV-CLUSTER) compared to the MCL-BCRP (24) approach:

Protocol	**MCL-BCRP**	**AOMDV-CLUSTER**
Clusters formed	31	12
Dead clusters	14	3
Energy consumed	0,5 J	0,442284 J
Clusters alive at end	55%	75%

Table 3: Comparison results

5.5.4 Comparison

Our results show that our approach (AOMDV-CLUSTER) formed fewer clusters than the MCL-BCRP approach, but with significantly fewer inactive clusters at the end of the simulation. Furthermore, although our approach consumed slightly less energy than MCL-BCRP, it managed to maintain a higher percentage of active clusters until the end of the simulation, indicating greater efficiency in the use of network resources.

6 Conclusion

The reactive AOMDV protocol is efficient and can reduce end-to-end delays, packet loss and increase the rate of successful packet delivery. However, it still suffers from high power consumption due to its flat architecture. This paper uses a preventive approach based on node clustering to reduce energy consumption and increase network lifetime. The proposed AOMDV-clus protocol clusters the network into groups and selects a group leader from each cluster using a new technique. This division allows us to reduce network overload and consequently reduce the number of packets processed by each sensor, thereby increasing the lifetime of a sensor. Our work's simulation results revealed our algorithm's effectiveness in reducing energy consumption and improving the lifetime of WSNs.. More specifically, we observed a significant reduction in energy consumption and an increase in packet delivery rate compared with existing approaches. Indeed, an appropriate distance threshold enables optimal cluster size, minimizing redundant communications and energy consumption. In conclusion, our clustering algorithm proves to be an effective solution for energy management and performance optimization in WSNs. Implementing this approach in NS2 validates the efficiency of our algorithm and highlights its advantages over other existing approaches. Simulation results show a reduced number of dead nodes, a reduction in network overload and energy consumption, anda higher level of performance. and energy consumption, and an improved packet delivery success rate.

7 Limits and future work

Sensors used in WSNs often have limited capabilities in terms of energy storage and management. We could not cover the impact of other types of energy harvesting technologies (such as solar or kinetic powered sensors).

The protocols used for WSNs (e.g., ZigBee, LoRa, NB-IoT) play a key role in energy management. Since the work focuses on the AOMDV protocol, we may not address the energy implications related to other types of protocols. The energy consumption related to data transmission is a key factor that can be influenced by the choice of protocol.

In energy management of sensor networks, security of data and communications is essential. The work does not consider security issues related to energy management (e.g., denial of service attacks affecting sensors), this can be a significant limitation.

For future work in energy management of sensor networks, here are some improvements that could be considered to further this topic:

- Integration of AI and ML technologies for more intelligent and adaptive optimization solutions.
- Optimization of communication between sensors
- Analysis of the impact of varied environments innovative approaches to ensure that energy management systems meet security standards while minimizing the risks of attack

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