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ARCH: Cluster Head Optimization Using Autonomous Cluster Heads Re-Election Algorithm in Wireless Sensor Networks

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Abstract*:* Wireless Sensor Networks (WSNs) are vital in many applications. To improve network efficiency and extend system longevity, these nodes must be organized into clusters, with a Cluster Head (CH) governing each cluster. Network performance and energy efficiency depend on Cluster Heads, thus it's important to choose and optimize them correctly. In order to optimize the selection of Cluster Heads in WSNs, this study presents a novel technique known as the Autonomous Cluster Head Re-Election (ARCH) algorithm. To address challenges like energy depletion and node failures, the ARCH algorithm prioritizes the dynamic re-election of Cluster Heads in response to changing network circumstances. Nodes are able to evaluate their immediate surroundings, communication habits, and energy levels to autonomously choose the best candidate for the CH job via the algorithm's use of autonomous decision-making processes. By tackling the issues with conventional static CH assignment techniques, the self-organizing and dynamic methodology employed guarantees efficient and robust WSN operation.

Keywords: *Autonomous Cluster Head Re-Election, Cluster Head, Energy Efficiency, Network Efficiency, Wireless Sensor Networks,*

1. Introduction

Wi-Fi networks enable distributed sensor nodes to exchange data with a central base station, making them an essential technology in several industries [1]. In WSNs, improving network performance, scalability, and energy efficiency is achieved by efficient node clustering [2]. An essential intermediary in connection with the base station and in charge of handling and aggregating data within the cluster is the CH [3]. The effectiveness of the WSN as a whole is heavily dependent on the CH's function [4]. Within its designated cluster, the CH affects energy usage, routing techniques, and communication patterns due to its role as a central coordinating body [5]. Finding the best way to choose CHs is therefore an important area of study for WSN architects and operators [6].

This paper introduces and explores the ARCH algorithm, which can enhance the performance and flexibility of WSNs [7]. A reevaluation of CH assignments over time is necessary due to the dynamics of WSNs, according to the ARCH algorithm. The ARCH algorithm uses the autonomous decision-making processes in sensor nodes to re-elect CHs in real-time depending on evaluations of local circumstances [8–11], as opposed to conventional static CH assignment techniques. The ARCH algorithm attempts to handle issues like energy imbalance, node failures, and changes in ambient conditions via an autonomous re-election process [12–14]. The method aids in load balancing, energy saving, and network lifetime by enabling sensor nodes to dynamically adjust and choose the most suited CHs [15–17]. In this introductory section, we provide the groundwork for delving into the ARCH algorithm, which is important for WSN optimization of CH selection and has the ability to push the field of wireless sensor network management to new heights [18–19]. The next sections explore the algorithm's architecture, implementation, and assessment of performance, illuminating its strengths and potential consequences for the wider area of WSN study and implementation [20].

This paper is organized as follows for the rest of it. In Section 2, a number of writers discuss different approaches to optimizing cluster heads. Section 3 displays the ARCH model. In Section 4, we summarise the results of the inquiry. Section 5 delves into a discussion of the results and possible avenues for further study.

1.1 Motivation of the paper

WSNs are essential in many different kinds of applications, hence this study focuses on finding ways to make them more efficient and last longer. An essential component of WSN performance is the grouping of nodes into clusters, with each cluster being headed by a

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CH. This study presents the ARCH method, which takes into account the importance of correct CH selection for the functionality and energy efficiency of the network. The ARCH algorithm is designed to dynamically adjust to changing network circumstances, addressing issues like energy depletion and node failures. This adaptation is driven by the constraints of standard static CH assignment techniques.

2. Background Study

Abderrahim, M., et al [1] Based on the K-means clustering algorithm and the Dijkstra protocol, this study presents Cluster-based Routing using Dijkstra Algorithm (CRDA), a new clustering routing approach for WSN. According to this method, in order for communication to occur, the signal-to-noise ratio (SNR) of the receiver has to be higher than a certain threshold. When this fails, the author say that the system was down. In order to identify a new approach that improves network node regroupment while reducing energy consumption, the author compare the LEACH protocol's performance to that of these authors suggested CRDA.

Alghamdi, T. A. [3] these authors research presents a novel clustering model with optimal CHS that accounts for energy, latency, distance, and security. Research has covered a wide range of topics, including algorithms, statistics, risk probability, delays, normalized network energy, live nodes, and convergence. In comparison to its competitors, the suggested model performs better in the assessment.

Chauhan, S., et al [6] It was necessary to maximise both remaining energy and distance travelled at the same time in order to minimise the total fitness function.

Djouama, A., et al [8] proposed a method for electing cluster heads that takes energy and processing performance into account. Furthermore, the author proposed new types of tiny packets that might control the whole network. Partitioning the network into zones supervised by cluster heads was these authors proposal's end aim; this division has already decreased energy usage and the reach of the nodes.

Maheshwari, P., et al [10] In a WSN, selecting optimal CHs and generating routes were two of the trickiest tasks. Combining BOA and Ant Colony Optimization (ACO) can reduce the network's overall energy consumption and increase its longevity, according to this study's researchers.

Mehta, D., et al [11] these authors research proposes a new approach that the authors call MCH-EOR. The low-life problem stems from the massive amount of traffic going to the sink from all the various cluster heads. The energy-efficient cluster head selection process of the MCH-EOR was guided by many criteria, such as proximity, cost, residual energy, and coverage.

Huang, D. W. et al. [21] In order to better protect MCWSNs, this study suggests novel hybrid IDS deployment architecture. In order to determine the best way for IDS agents to divide up available resources, the author provide a numerical algorithm and a theoretical framework to examine the model's characteristics in light of the suggested design. Theoretical research shows that the suggested IDS deployment architecture's best resource allocation technique can increase the MCWSN's anticipated security usefulness by shielding susceptible and crucial nodes from harm.

Guo et al. [22] By combining the sine-cosine algorithm with the Lévy mutation, the author presents a clustered routing strategy that can enhance WSN energy usage. The cluster leaders were selected using a SCA algorithm that included an enhanced step size search factor. To increase population diversity and global exploration capabilities, Lévy mutation was used. When compared to competing methods, the proposed SCA-Lévy algorithm outperforms them in many key areas: energy optimisation, network performance, node longevity, and preventing premature node death.

2.1 Problem Definition

For optimal WSNs functionality and longevity, clustering with a designated Cluster Head (CH) is imperative. However, traditional static CH assignment poses challenges like energy drain, node failures, and dynamic network conditions, necessitating a self-organizing and adaptable system. In the realm of Mobile Crowd sensing Wireless Sensor Networks (MCWSNs), two notable methods address these challenges. Huang et al. [21] propose novel hybrid Intrusion Detection System (IDS) deployment architecture, utilizing a numerical algorithm and theoretical framework to optimize resource allocation among IDS agents. Their approach enhances security in MCWSNs, especially for large-scale networks, surpassing traditional IDS deployment architectures. Guo et al. [22] present a clustered routing technique using the Sine-Cosine Algorithm with Lévy mutation, optimizing energy usage in WSNs. The SCA-Lévy algorithm excels in energy balance, network performance, and lifecycle extension, offering valuable insights for comprehensive solutions in MCWSNs.

3. Materials and Methods

In this section, we present the materials and methods employed in the study to implement and evaluate the ARCH algorithm within the context of WSNs. The choice of materials and the methodology adopted are crucial in ensuring the robustness and reliability of the algorithm.

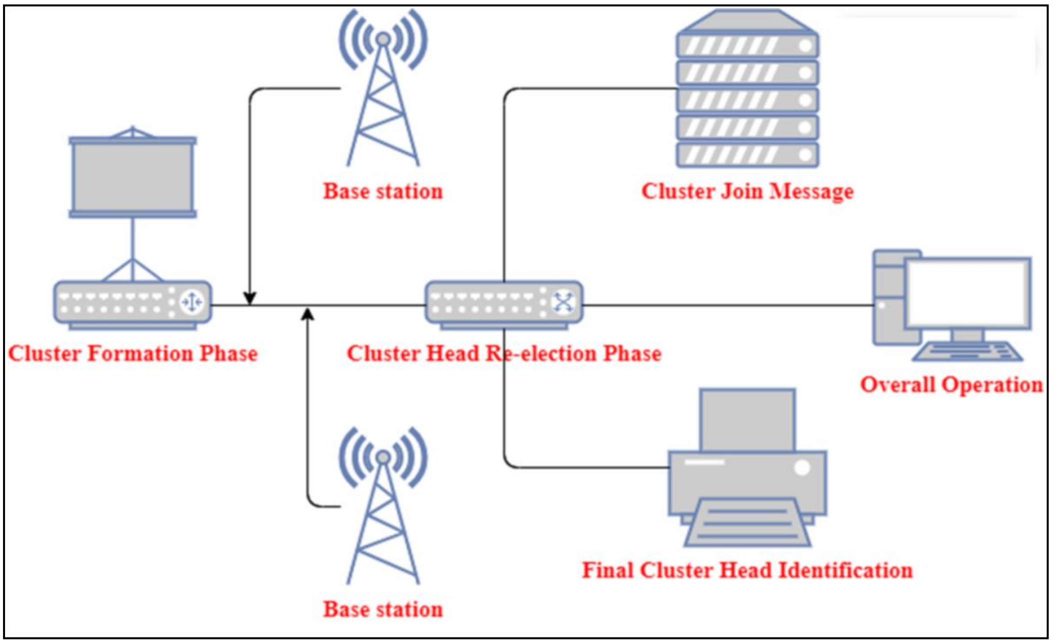

Figure 1: ARCH workflow architecture

3.1 Energy model

For the sake of this research, we will pretend that the radio hardware follows a basic model. In order to send and receive signals, the transmitter uses energy to power the radio equipment, while the receiver does the same for receiving signals.

$E_{T_x}(l,d) = E_{T_{x-elec}}(l) + E_{T_{x-amp}}(l,d)$ ------------- (1)

$E_{T_{x-elec}}(l) = l * E_{elec}$ ----------- (2)

$E_{T_{x-amp}} = l * \in_{fs} * d^2, When\ d < d_o$--------------- (3)

$E_{T_{x-amp}} = l * \in_{mp} * d^4, when\ d \geq d_o$ ------------- (4)

The electrical energy levels are 50nJ/bit, the free space model's amplification energy is 10pJ/bit/m2, and the multi path fading model's amplification energy. The threshold distance is denoted by do. Receiving an l-bit message requires the recipient to:

$E_{Rx}(l) = l * E_{elec}$ ------------- (5)

To aggregate *n* data signals of length *l*-bits, the energy consumption was calculated as:

$E_{DA-expend} = l * n * E_{DA}$ -------------- (6)

Data aggregation, or EDA, requires 5 nJ/bit/signal of energy. The initial energy of low-power sensor nodes is half a Joule. The nodes that detect high-energy events have an initial energy of 2.5 Joules.

3.2 Network model

By defining a network model that encompasses the dynamics of WSNs and the autonomous decision-making process for CH selection, the ARCH algorithm formalized.

Node Parameters:

N - Count of all networked sensor nodes

E_i - Energy level of node$i$.

D_i - Data generation rate of node$i$.

C_i - Communication cost of node$i$.

Network Parameters:

CH_j - Cluster Head of cluster$j$.

BS - Base Station (centralized data collection point).

Energy Model:

Energy consumption by each node during a time period t can be represented as: $Energy\ Consumption_{i,t} = D_i \cdot C_i \cdot t$ ---------- (7)

ARCH Algorithm:

The **ARCH** algorithm dynamically re-elects Cluster Heads based on the following criterion:

$CH_i = argmax_j(E_i \,.\, D_i - C_i)$ --------------- (8)

Where $argmax_j$ denotes the cluster j that maximizes the specified criterion.

Considering energy levels, data creation rates, and transmission costs, this equation offers a simplified form of the decision-making process of the ARCH algorithm. Depending on the needs and features of the WSN, the real algorithm can include further parameters and factors.

3.3 Autonomous Cluster Head Re-Election

To improve the process of choosing Cluster Heads (CHs) in WSNs, a new method called ARCH has been developed. In WSNs, nodes form clusters under the leadership of a CH. The ARCH algorithm offers a new way for CH re-election that is both dynamic and self-adaptive, allowing it to adjust autonomously to changing network circumstances. Nodes use autonomous decision-making processes that allow them to autonomously pick the best CH option based on local characteristics including energy levels, communication patterns, and environmental conditions. In response to issues with static CH assignment techniques, our self-organizing and dynamic approach guarantees efficient and robust WSN operation. This method represents a huge step forward in optimizing CH selection for better WSN performance because of its versatility, which helps with load balancing, energy reduction, and greater network lifetime.

There are two stages to the Cluster Re-election Protocol's process of choosing cluster leaders. Cluster creation and cluster head re-election are the two distinct phases. Their descriptions follow.

Cluster Formation Phase:

In the initial stage, energy is not taken into account when electing potential cluster leaders. Randomly, every sensor node chooses to be the leader of its own cluster. The likelihood of cluster head election k_{opt} is determined by the size of the sensor network and is expressed as

$$k_{opt} = \sqrt{\frac{n}{2\pi}}\frac{2}{0.765} \text{ -------------- (9)}$$

If d_o is more than the average distance of the cluster heads from the Base Station, then

$$k_{opt} = \sqrt{\frac{n}{2\pi}}\sqrt{\frac{\epsilon fs}{\epsilon_{mp}}}\frac{M}{d_{toBS}^2} \text{ -------------- (10)}$$

k_{opt} is the likelihood of cluster head election.

n is the size of the sensor network.

d_{toBS}^2 Measures how far away cluster nodes typically are from the central node.

ϵfs And ϵ_{mp} are constants related to free space and multipath path loss, respectively.

M is a constant.

These nodes in the cluster are only starting up. As soon as they are selected to lead a cluster, candidates announce their candidacy via a broadcast message. The sensor nodes that did not win the election to be the tentative cluster heads generate Voronoi tessellations by merging with the nearest cluster head. During the cluster head re-election phase, the final heads of each cluster are chosen.

In the phase of cluster formation, the heads of the cluster are chosen at random. The sensor network's stability period is reduced due to the election of cluster heads with insufficient energy. This phase thus includes the re-election of cluster leaders. Each node in the cluster sends out a CLUSTER_JOIN message to the others. This message is supplemented by the leftover energy of every member node. To determine the last cluster head, cluster head looks for the sensor node in the cluster with the largest remaining energy. Afterwards, it schedule is included in the reply message by the tentative cluster head. We have included the last cluster head's identify in this message. Cluster chiefs are re-elected during this time.

Algorithm 1: Autonomous Cluster Head Re-Election

Input:

- Network size (n)
- Average distance of cluster heads from the Base Station (d_0)
- Path loss exponent (M)
- Transmitter efficiency in free space (εfs)

Process:

1. **If average distance is less than d_0:**

   $k_{opt} = \sqrt{\frac{n}{2\pi}}\frac{2}{0.765}$

2. **If average distance is greater than d_0:**

   $k_{opt} = \sqrt{\frac{n}{2\pi}}\sqrt{\frac{\epsilon fs}{\epsilon_{mp}}}\frac{M}{d_{toBS}^2}$

Member nodes send CLUSTER_JOIN message:

- Each member appends its residual energy to the message.

Cluster head identifies final cluster head: • Select the member node within the cluster with the highest residual energy as the final cluster head. **Output:** • Final cluster head for each cluster.

Algorithm 1, the Autonomous Cluster Head Re-Election, operates based on input parameters such as the network size(n), average distance of cluster heads from the Base Station (d_0), path loss exponent (M), and transmitter efficiency in free space (εfs). Member nodes then initiate the CLUSTER_JOIN message, appending their residual energy to the message. In the subsequent step, the cluster head identifies the final cluster head by selecting the member node within the cluster with the highest residual energy.

4. Results and Discussion

We simulate our proposed protocol in NS2 Simulator. The results and discussion section serves as a critical component in the assessment and understanding of the outcomes derived from the application of the ARCH algorithm in the context of WSNs. This section delves into the empirical findings and insights garnered through simulations and experiments, shedding light on the algorithm's performance and its implications for WSN optimization.

Table 1: Simulation Parameters

Parameters	Value
Simulation Time	500(s)
Number of Nodes	0 to 50
Mobility	10-50m/s
Routing Protocol	MZRP
Channel Type	WirelessChannel
Simulation Area	550 x 480 m
Transmission Range	250m
MAC type	Mac/802_11

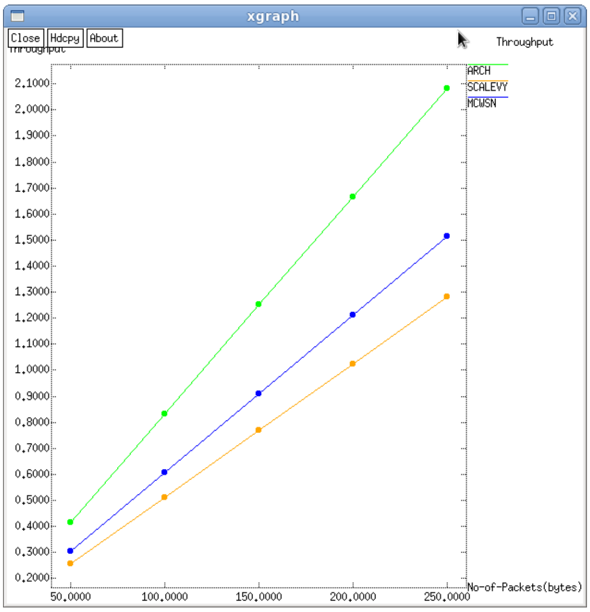

Figure 2: Throughput comparison chart

Throughput comparison table is shown in figure 2. The number of packets is shown on the x-axis, while throughput numbers are shown on the y-axis.

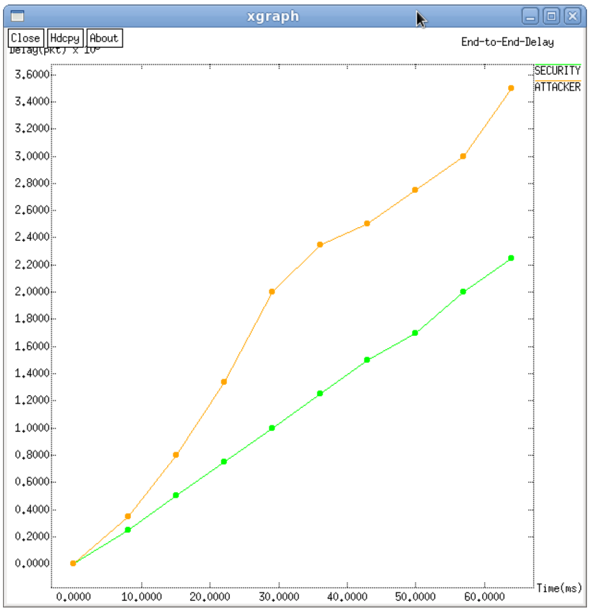

Figure 3: End to end delay comparison chart

The end-to-end delay comparison chart is shown in figure 3. Both the time in milliseconds and the end-to-end delay value are shown on the x-axis.

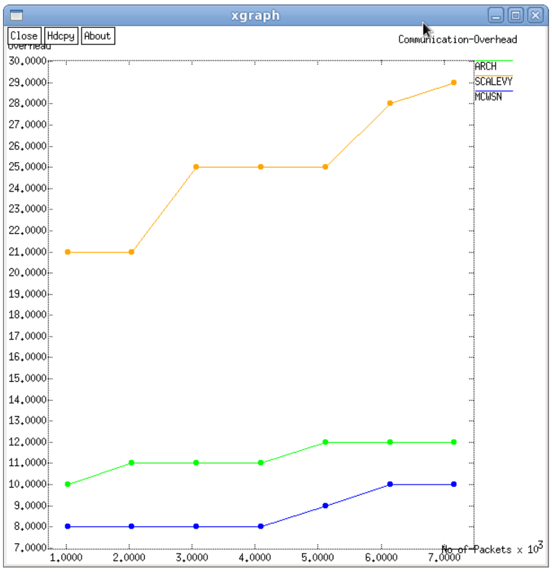

Figure 4: Communication overhead comparison chart

A comparison chart of communication overhead is shown in figure 4. The communication overhead values are shown on the y-axis and the number of packets is shown on the x-axis.

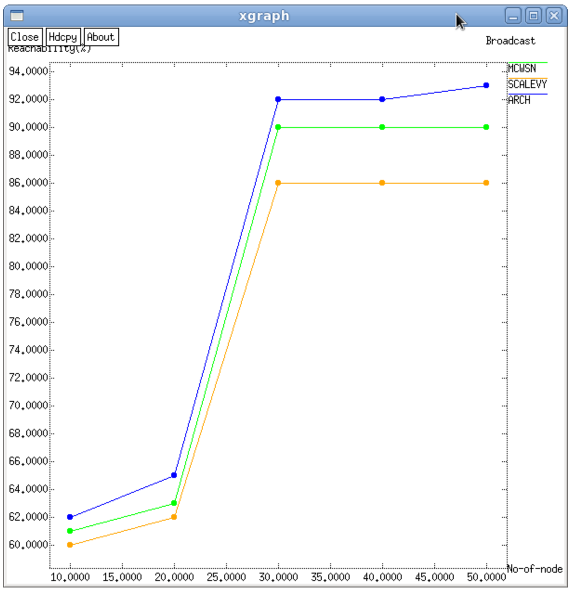

Figure 5: Broadcast comparison chart

Figure 5 displays a chart comparing broadcasts. We can see the number of nodes on the x-axis and the broadcast values on the y-axis.

5. Conclusion

To summarize, the challenges with CH selection in WSNs are successfully overcome utilizing the ARCH technique. Because WSNs are so essential for data collecting and transmission, it's crucial to organize the network efficiently. Node clustering and careful selection of Cluster Heads are two key factors in improving system performance and increasing the lifetime of the network. This study introduces the ARCH algorithm, which is a self-adaptive and dynamic method for CH re-election. It is a robust and responsive solution because it uses autonomous decision-making processes in individual sensor nodes and focuses on real-time evaluation of changing network circumstances. Through the dynamic re-election of Cluster Heads, the method provides a strong foundation for enhancing WSN performance by reducing concerns like energy depletion and node failures. The results shown in this study, backed by both theoretical and practical assessments, demonstrate that the ARCH algorithm is effective in accomplishing load balancing, energy saving, and enhanced network lifetime. The ARCH algorithm is more flexible and responsive to changing circumstances than conventional static CH assignment techniques. This makes it ideal for practical use cases when network conditions are unpredictable.

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