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Cluster-based routing protocols through optimal cluster head selection for mobile ad hoc network

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ABSTRACT

Mobile ad hoc networks (MANETs) operate without fixed infrastructure, with mobile nodes acting as both hosts and routers. These networks face challenges due to node mobility and limited resources, causing frequent changes in topology and instability. Clustering is essential to manage this issue. Significant research has been devoted to optimal clustering algorithms to improve cluster-based routing protocols (CBRP), such as the weighted clustering algorithm (WCA), optimal stable clustering algorithm (OSCA), lowest ID (LID) clustering algorithm, and highest connectivity clustering (HCC) algorithm. However, these protocols suffer from high re-clustering frequency and do not adequately account for energy efficiency, leading to network instability and reduced longevity. This work aims to improve the CBRP to create a more stable and long-lasting network. During cluster head (CH) selection, nodes with high residual energy or degree centrality are chosen as CH and backup cluster head (BCH). This approach eliminates the need for re-clustering, as the BCH can seamlessly replace a failing CH, ensuring continuous cluster maintenance. The proposed modified cluster-based routing protocol (MCBRP) evaluated network simulator 2 (ns2) demonstrates that MCBRP is more energy-efficient, selecting optimal CH and balancing the load to enhance network stability and longevity.

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1. INTRODUCTION

Wireless networks serve as essential communication infrastructures that facilitate connectivity without the reliance on wired materials or cables. They offer pervasive communication capabilities, enabling continuous connectivity through portable devices that require access points or base stations. While conventional wireless networks necessitate stable infrastructure, mobile ad hoc networks (MANETs) provide a decentralized alternative where wireless nodes communicate directly without fixed access points. These wireless networks are categorized into infrastructure-based and infrastructure-less networks [1], [2]. In infrastructure-based setups, wireless nodes communicate via a wired network connected to access points or base stations. In contrast, infrastructure-less networks, exemplified by MANETs, eliminate the need for fixed access points or base stations, with mobile hosts serving as both hosts and routers to generate and relay packets [3], [4].

Routing protocols play a pivotal role in MANETs as they dictate the path for transmitting data packets from the source to the destination. These protocols are typically classified into proactive, reactive, and hybrid categories. Proactive protocols, while efficient in maintaining routing information for all nodes, incur high overheads due to continuous updates. Reactive protocols, exemplified by dynamic source routing (DSR) and ad hoc on-demand distance vector (AODV), determine routes when required, thereby reducing overhead but introducing delays during route discovery [5]. Hybrid protocols, incorporating elements of both proactive and reactive approaches, aim to strike a balance to minimize latency and broadcasting. Despite their advantages, MANETs encounter challenges such as limited battery power, constrained bandwidth, routing overhead issues, and delays in route discovery [6]. The high mobility of nodes results in frequent changes in network topology, posing difficulty in maintaining network stability. Clustering emerges as a strategic mechanism to address this concern. The cluster-based routing protocol (CBRP) exemplifies such an approach by organizing nodes into clusters, each overseen by a cluster head (CH) responsible for facilitating communication within and between clusters.

Clustering algorithms in MANETs operate in either active mode, where nodes actively exchange information to designate a CH, or passive mode, where information is incorporated during data transmission. The cluster formation stage involves the meticulous selection of a CH based on performance metrics, while maintenance necessitates the periodic re-selection of CH as circumstances require. Notable clustering algorithms include lowest ID (LID), highest connectivity clustering (HCC), and the weighted clustering algorithm (WCA) [7]-[9]. The core challenge in clustering lies in identifying optimal and robust CH and gateways, as well as determining the ideal cluster size to maximize throughput while minimizing energy consumption. Efficient clustering plays a vital role in reducing communication costs and energy expenditure, particularly in inter-cluster communication scenarios. To enhance clustering efficiency in MANETs, algorithms like the optimal stable clustering algorithm (OSCA) integrate multiple metrics such as node degree, distance, mobility, and battery power into the CH selection process. However, there is a pressing need for enhancements to address energy consumption issues and improve operational efficiency during cluster maintenance. Implementing modified approaches to the CBRP holds promise for more effective clustering by incorporating these critical factors, ultimately fostering enhanced network performance and lower energy consumption levels. MANETs find applications across various domains and remain a focal point in research due to challenges posed by limited battery capacity, RREQ flooding concerns, restricted bandwidth, and network scalability [10]-[12]. In the LID clustering algorithm [13], each node is assigned a unique ID and CH are designated based on the node with the LID after broadcasting hello packets. Conversely, the Max-Min d-cluster formation algorithm [14] prioritizes the cluster size as a primary performance metric. However, challenges arise in specifying the optimal value of 'd,' neglecting factors such as mobility and load balancing during CH selection, and impacting network stability negatively.

Research by Talapatra and Roy [15], the described algorithm leverages diverse performance factors to assess the suitability of a node for selection as a CH. By incorporating mobility, battery capacity, node degree, and distance or degree differential in calculating a combined weight, the algorithm aims to identify nodes with the smallest combined weight as potential CH. Referred to as the WCA, the primary aim is to appoint CH impartially, avoiding bias towards specific performance metrics. This methodological approach of selecting CH based on multiple performance metrics enhances network performance and stability significantly. According to Uikey [16], the mobility-based metric for clustering (MOBIC) introduces a local mobility metric to enhance the cluster formation process. This algorithm first computes pair-wise relative mobility metrics and subsequently aggregates them to determine an overall relative mobility metric before transmitting the next broadcast packet to neighboring nodes.

According to Bhatia and Verma [17], the mobility-based d-hop clustering algorithm (MobDHop) estimates the stability of clusters based on the relative mobility of cluster members, and the diameter of the cluster is flexible. In this algorithm nodes that have similar moving patterns are grouped in one cluster. According to Aissa and Belghith [18], node-based cluster routing algorithm (NBCRA) this algorithm takes four parameters to calculate the ability of the node (degree of a node, battery power, transmission power, and stability of node) and the node having a maximum ability is elected as CH. The strong point of this algorithm is that it has a better performance than WCA.

The primary objective of this research is to introduce an enhanced CBRP that refines CH selection processes and gateway management by integrating crucial metrics such as relative mobility and residual battery energy. The core focus is on reducing overhead, curbing energy consumption, and optimizing network throughput. Key contributions of this study encompass the implementation of a backup cluster head (BCH) mechanism to facilitate uninterrupted cluster maintenance, the formulation of an energy-efficient CH selection algorithm, and the integration of mobility-aware clustering methods to bolster network stability. These enhancements collectively extend network longevity while fostering a substantial reduction in energy consumption levels.

2. METHOD

A comprehensive understanding of the intricacies within the realm of MANET routing protocols and clustering algorithms is vital, necessitating the exploration of a diverse array of literature sources such as research papers, books, journal articles, and relevant documents. Through an extensive review of existing literature, the techniques and methodologies employed in the development of clustering algorithms are meticulously examined and evaluated. This thorough examination serves as a foundational step in gaining insights into the nuances of MANET protocols, paving the way for informed decision-making and the advancement of innovative clustering algorithms.

2.1. Algorithm design

Drawing insights from existing literature, we identified a critical gap and proposed an algorithm designed to enhance CH stability, consequently leading to a boost in network throughput and a reduction in energy consumption during the cluster formation phase. Our algorithm focuses on the meticulous selection of a primary CH and a BCH based on various factors such as battery power or node centrality for primary head selection, and member node proximity and relative mobility for membership inclusion. Following cluster formation, the algorithm deliberates on determining the optimum number of nodes within each cluster. In the subsequent cluster maintenance phase, the CH undertakes priority calculations based on residual energy levels and node mobility. Notably, unlike immediate CH selection during routine maintenance, our algorithm defers to the secondary CH for the election of a new backup node, a process facilitated through the calculation of priority factors. Through this systematic approach, our proposed algorithm aims to fortify cluster stability, streamline cluster management, and ultimately enhance network efficiency and longevity.

In the general context, the selection process involves identifying a coordinator node or CH, along with choosing inter-cluster links (gateway nodes). The selection of the CH is based on performance metrics such as residual energy levels of nodes or degree centrality, whereas gateway nodes are designated by evaluating the distance between the source node's CH and the destination node. Furthermore, in this phase, a backup node is chosen utilizing the same parameters employed in CH selection, serving as an alternative CH when the primary head transitions out of the cluster, thereby mitigating communication overhead during re-clustering processes.

Following CH selection, a cluster of mobile nodes is formed based on their mobility patterns and proximity to the CH. Nodes exhibiting similar movement trajectories or those close to the CH are grouped within a cluster. Moreover, the algorithm considers the optimal number of nodes that a CH can efficiently manage, ensuring optimal cluster size and operational efficiency.

2.2. Evaluation method

We simulated the proposed work on network simulator 2 (ns2) and compared what is already done in CBRP. We evaluate our work with an OSCA regarding the throughput of the network and energy consumption.

3. PROPOSED SYSTEM

MANET is located anywhere, and a flat structure network encounters network scalability problem with large network sizes, especially with low battery power and high-speed mobile nodes. In MANET when the network size and number of nodes exceed its optimal value reduces network performance, and there is high energy consumption during CH selection. The major challenges to creating energy-efficient and optimal CH selection algorithms are related to the consideration of parameters that are used to select CH. In this section, we discuss the new algorithm that we proposed based on the gap identified in the introduction part. CBRP protocol has a certain number of clusters and there is a special node called CH that is responsible for reviving data from member nodes and will pass to the gateway.

In enhancing the CBRP, the utilization of advanced algorithms for both cluster formation and maintenance is imperative. During the cluster formation phase, a CH is meticulously selected based on criteria such as node degree centrality or residual energy levels, while member nodes are subsequently incorporated into this cluster based on their proximity and relative mobility until reaching an optimal node count. The selection of the CH prioritizes node degree centrality as the primary criterion, followed by residual energy levels. In scenarios where mobile nodes exhibit equivalent centrality degrees, the selection is determined by residual energy levels. Metrics serve as crucial parameters that gauge the competency of nodes, thereby refining the cluster formation and CH selection algorithms. In the utilization of multiple performance metrics, a single metric is employed for optimal selection. Our approach leverages diverse performance parameters during cluster formation, CH selection, and maintenance to enhance protocol efficiency. Given the core focus of our research on cluster formation and optimal CH selection, the forthcoming discussions will delve into the intricacies of parameter calculation in MANET networks to amplify the effectiveness of our proposed clustered network.

In Figure 1, the flowchart of the proposed algorithm is presented. Initially, a mobile node is deployed and assesses parameters for assigning a CH. Subsequently, the CH is chosen based on a high degree of centrality or residual energy. Once the CH is selected, member nodes join a specific CH based on the illustrated parameters. The mobile node continues to connect to the CH until it achieves its optimal value.

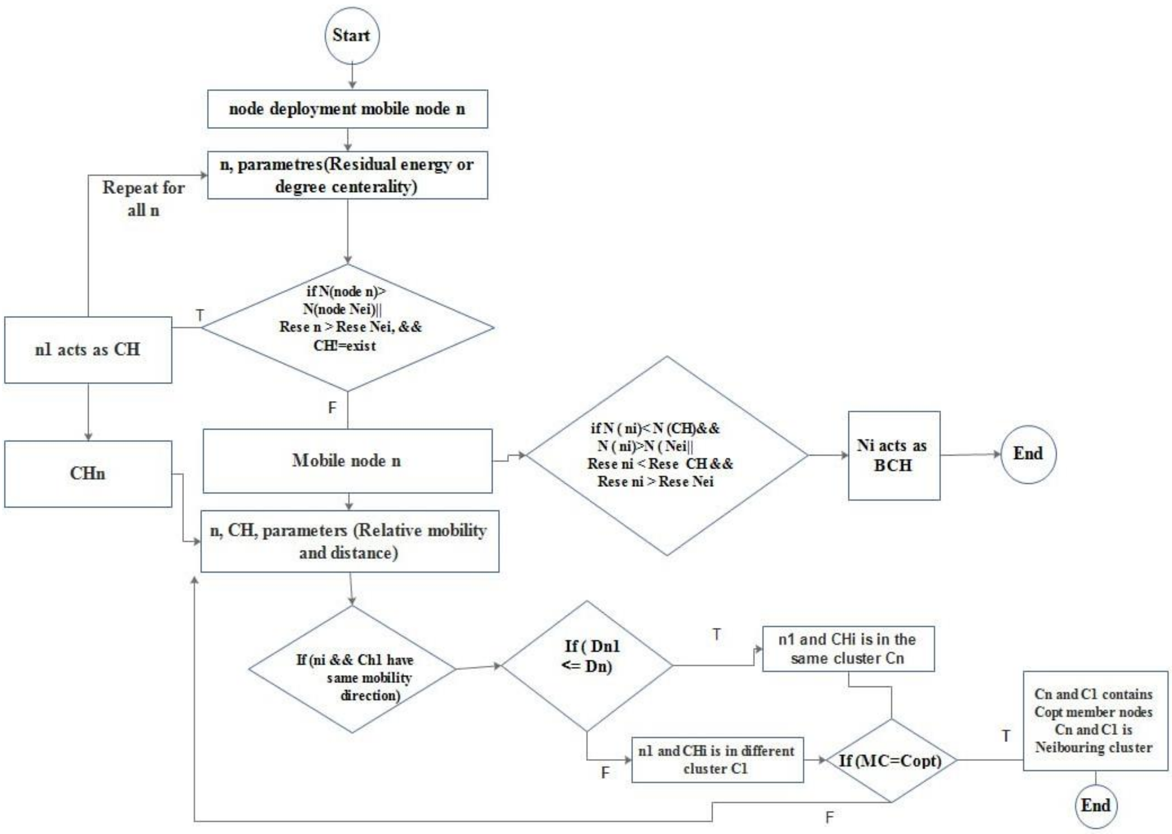

Figure 1. The flowchart of the proposed system

4. RESULT

The simulation environment was utilized to implement our modified algorithm, a critical step in testing new networking protocols and modifications to existing ones. Various network simulators, including OPNET, QualNet, NS 2, Ns3, OMNET++, NetSim, REAL, J-sim, and GloMosim, offer distinct features categorized by factors such as open-source availability, simplicity, complexity, language support, platform support, licensing, GUI, and animation capabilities [18]-[21]. Our proposed work was implemented using open-source software, specifically network simulator version 2 (ns2.35), uniquely designed as an open-source event-driven simulator tailored for computer communication networks [21]. Graphical representation of results utilizes the Xgraph tool, while interactive viewing is facilitated through the network animator (NAM visualization); additionally, AWK files are employed for text-based delivery of simulation results [22], [23]. NAM benefits significantly from its robust integration with ns, enabling comprehensive protocol details to be extracted from simulations [24].

The evaluation encompassed a comparative analysis between our proposed approach and the existing CBRP protocol. This assessment involved the utilization of a text file and Xgraph for the examination and interpretation of simulation outcomes. The key performance indicators assessed during this evaluation were network throughput and protocol energy consumption presented in subsequent sections.

4.1. Performance evaluation

In our simulation, we integrated multiple performance metrics to extract valuable insights, focusing primarily on total energy consumption. In MANETs, energy is consumed during various operational phases such as idle periods, data transmission, and data reception, occurring across distinct layers including the application, network, and MAC layers. Managing energy consumption is especially challenging due to the limited battery capacity of each mobile node. Our system tackles this challenge by optimizing energy usage through the strategic selection of CH tasked with coordinating inter-cluster and intra-cluster communication. The assessment of total energy consumption within our proposed protocol encompasses all mobile nodes, encompassing both idle and active states. We conducted evaluations at different simulation time intervals to quantify the reduction achieved by our protocol, thereby enhancing its efficiency. Table 1 illustrates the total energy consumption comparison between the modified CBRP (MCBRP) and the existing CBRP protocol, showcasing superior energy efficiency in our proposed system.

Table 1. Energy consumption of MCBRP with CBRP

Simulation time	Energy consumption of MCBRP	Energy consumption of CBRP
5	9.6560	10
10	9.85431	10.2
15	9.92861	15.3
20	10	10.321
25	10.190	10.41230
30	10.2	10.41230
35	10.48912	10.41234

As depicted in Figure 2, the energy consumption escalates over time for the CBRB in contrast to the MCBRP. This trend underscores the supremacy of our proposed clustering algorithm over the existing OSCA clustering algorithm. Noteworthy, load balancing has a demonstrated impact on improving network performance. Therefore, our proposed method not only optimizes load distribution but also reduces average energy consumption and boosts throughput, as validated by the generalization of results.

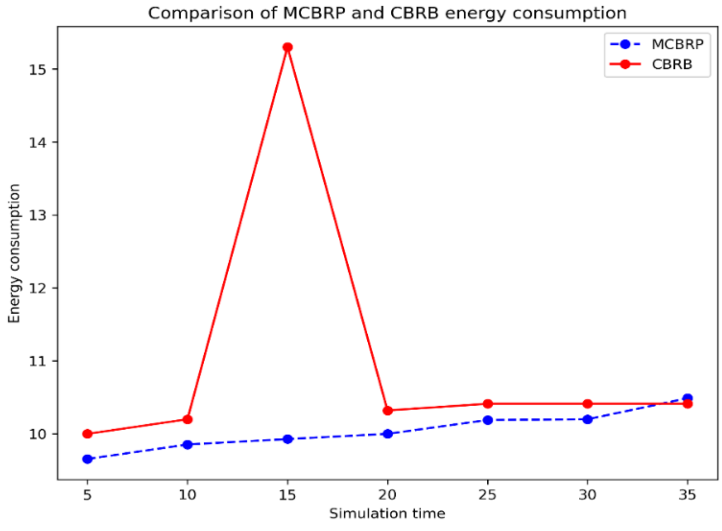

Figure 2. The energy consumption of MCBRP

As depicted in Figure 2 shows the average energy consumption of both the existing OSCA clustering algorithm and the MCBRP clustering algorithm as simulation time increases. As clearly shown from the graph the average energy consumption of the modified clustering algorithm for CBRP is proportionally lower than that of the existing clustering algorithm. Hence, the proposed clustering algorithm is more energy-efficient than the existing work.

4.2. Throughput of the network

The throughput of a network represents the total amount of data transmitted over a specified period. The simulation results comparing the CBRP and the MCBRP in terms of throughput are provided in the table. Additionally, Table 2 illustrates the throughput achieved through the proposed CH selection method.

Table 2. Simulation result of CBRP and MCRB in terms of throughput

Simulation time	Throughput of MCBRP	Throughput of CBRP
5	0.39120	0.2567
10	0.5102	0.28912
15	0.5612	0.35012
20	0.56781	0.39145
25	0.59162	.044312
30	0.721	0.44312

As illustrated in Figure 3, the network throughput demonstrates a positive correlation with simulation time. The graphical representation highlights the superior performance of our proposed clustering algorithm compared to the existing OSCA clustering algorithm. Given that load balancing has been shown to significantly improve network performance [25], our approach focuses on not only optimizing load distribution but also reducing average energy consumption and enhancing throughput in a broader context.

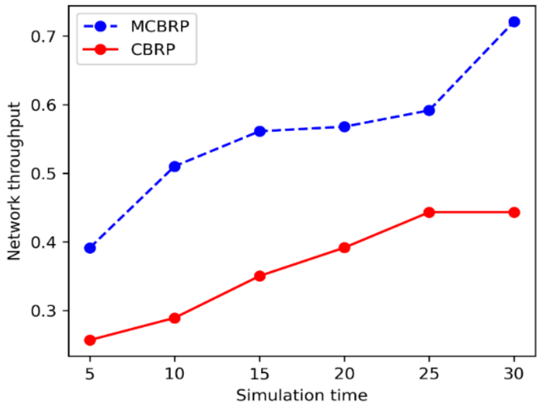

Figure 3. The throughput of the network

5. CONCLUSION

Wireless networks have revolutionized communication by eliminating the dependence on physical cables, facilitating seamless connectivity anytime and anywhere. While mobile devices typically rely on access points or base stations for connectivity, clustering within ad hoc networks presents unique challenges due to the dynamic network topology. This study introduces innovative strategies to enhance the CBRP in MANETs, specifically targeting energy efficiency in both inter-cluster and intra-cluster communications. The proposed modified clustering algorithm considers essential factors like relative mobility, distance, residual energy, and degree centrality to optimize cluster member selection, ultimately extending the operational lifespan of mobile nodes. By establishing a self-configuring and self-managing network model, our system enhances communication efficiency within and between clusters by strategically appointing proficient CH based on predefined criteria before network establishment. Key aspects of our approach include defining limits on the maximum node degree a CH can manage, implementing load-balancing strategies to prevent resource depletion, and ensuring cluster stability without frequent restructuring. In cases of CH failure, a seamless transition occurs as a BCH swiftly assumes control, ensuring continuous network operation. Overall, our method significantly improves the CBRP protocol by enhancing CH selection, formation, and maintenance processes, leading to reduced energy consumption and enhanced network throughput. The successful implementation and evaluation of the MCBRP algorithm using ns2.35 demonstrate substantial improvements over the existing OSCA. However, the validation of this method in practical applications requires experimentation in real-world networks using physical devices. This aspect represents both future work and a limitation of this study that needs improvement.

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