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A Novel Link Failure Prediction in Cluster Based Routing Protocol for MANETs

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Abstract: The mobile adhoc network (MANET) has attracted considerable attention from researchers due to its dynamic and versatile nature. Graph clustering algorithms can be more effective than optimization algorithms in modeling and analyzing networks because these algorithms arrange nodes into clusters based on their connectivity. According to this context, a graph kernel-based clustering algorithm (GKCA) was developed for MANETs by combining the d-hop graph kernel and clustering scheme. Additionally, it uses the shortest route to connect multiple cluster head (CH) nodes for data transfer. MANETs face challenges such as changes in network structure and disruptions in communication links, which result in an increase in route discovery requests and longer mean end-to-end delays (MED) due to longer link reconnect times. Hence, this article proposes the GKCA with link failure prediction (GKCA-LFP) in MANETs to prevent path failures resulting from node mobility. The GKCA is initially used to determine the cluster size and CH nodes. The shortest route is used to connect the CHs for data transfer. Then, the LFP strategy is introduced at this stage to maintain the path. This strategy aims to predict the current link status based on mobility and position information to prevent failure conditions and minimize packet loss ratio (PLR). The GKCA-LFP algorithm can choose more stable shortest paths to connect CHs for data transfer, resulting in decreased MED and PLR. The extensive simulations show that the GKCA-LFP algorithm outperforms the GKCA, AMAC, MARP-HO, and RS-GG algorithms in MANETs. Specifically, for 100 nodes, the GKCA-LFP algorithm achieves a 1.4% control packet ratio (CPR), 0.8% PLR, and 455µs MED. Additionally, for nodes with a mobility speed of 20m/s, the GKCA-LFP algorithm achieves a 1.2% CPR, 2.3% PLR, and 120µs MED.

Keywords: Mobile adhoc networks, Clustering, Graph kernel clustering, Path maintenance, Link failure prediction.

1. Introduction

The MANET is a self-organizing network of wireless mobile nodes that operate without a central base station or centralized control. Both the military and civilian sectors heavily rely on MANETs. However, there are limitations to this technology, including restricted data transfer, narrow bandwidth, low power, and unreliable links [1]. Optimal routing and high-performing nodes are crucial for maximizing data transmission capacity and prolonging longevity [2]. The architecture of a MANET can be classified into two types: distributed and cluster. All nodes in a distributed network are crucial, and the network's topology adapts dynamically to accommodate mobile nodes [3].

For enhanced functionality and processing power, clustering networks are essential. In a MANET, a mobile cluster consists of three types of nodes: CHs, border nodes, and cluster members. CHs are central nodes that have strong connections to other clusters. The nodes at the borders of the cluster are neighboring nodes from other clusters. Nodes within a cluster that do not serve as the CH are called cluster members [4]. Thus, the limitations of routing protocols can be overcome, data transmission quality can be enhanced, and network scalability can be expanded due to clustering [5]. MANET clusters enhance connectivity between mobile nodes and optimize resource utilization effectively. They establish a layered network environment to protect the MANET framework [6]. The main characteristic of a MANET is its hierarchical clustering, which enables the division of larger networks into smaller, more manageable parts.

The ancient field of graph theory is a valuable resource for simulating and analyzing modern Internet infrastructure [7]. Euler's 1736 solution to Konigsberg's bridge problem has significant applications in fields such as logistics, internet technology, mobile communication, cloud computing, and artificial intelligence [8]. Graphs in graph theory are abstract representations that can be generated without any practical constraints. Timing graphs offer a compromise between time and static graph traversals [9]. By representing the Postman issue as an undirected weighted graph, researchers can analyze hidden features and patterns of information [10]. Graph mining learning methods have been developed to address issues in the areas of the internet, neural networks, and artificial intelligence. Traditional chart analysis is insufficient for learning from data, which has led to the development of these methods.

From this perspective, Song et al. [11] introduced the graph kernel theory and discussed the optimization of both graph kernel and multi-graph kernel. The authors also discussed the basic principles of the d-hop graph kernel. Additionally, they proposed the GKCA that combines the d-hop graph kernel with a clustering method specifically tailored for MANETs. It used the shortest route to connect different CHs, enabling efficient data transmission. On the other hand, MANETs frequently face challenges, such as changes in network structure and disruptions in communication links, despite using the shortest route for data transfer. These disruptions can result in more route discovery requests and longer MED due to the extended time it takes to reconnect links.

Therefore, this manuscript proposes the GKCA-LFP for MANETs. The main goal of this study is to prevent path failures caused by node mobility. Initially, the GKCA is used to determine the cluster size and CH nodes. The shortest route is used to connect the CHs for data transfer. At this stage, the LFP strategy is introduced for path maintenance. This strategy intends to forecast the present link status to prevent failures and minimize data loss according to the mobility and position details. Thus, the GKCA-LFP can select more stable shortest paths to connect CHs for data transfer, leading to reduced MED and PLR.

The remaining sections are prepared as follows: Section 2 covers related works. Section 3 explains the GKCA-LFP, and section 4 demonstrates its effectiveness. Section 5 summarizes the findings and suggests potential future enhancements.

2. Literature survey

This section provides an overview of the relevant literature on the proposed GKCA-LFP. An efficient method called real-time reliable clustering and secure transmission (RRCST) was developed for MANETs [12]. First, the nodes were clustered, and the CHs were selected based on their previous forwarding nature and node information. The routing was done by a new scheme, which chooses the path according to the reliable transmission support (RTS), which includes the quality of service (QoS) value calculated for multiple paths. The CPR, PLR and MED were increased because it did not effectively handle link failures in the network.

A new reliable multipath routing protocol based on link quality and stability in urban areas (RMQS-ua) method was presented for MANETs [13]. The authors aimed to determine the route having high-quality links and resilient connections to ensure dependable information exchange. The link quality was evaluated by considering the signal-to-noise ratio and an improved packet acceptance rate. The stability of the link was determined using the exponential moving average. However, the MED was high because the source node (SN) and destination nodes (DNs) had to wait for a specific duration for path creation.

A mobility-aware routing protocol using hybrid optimization (MARP-HO) was developed for MANETs to improve the QoS in packet transfer [14]. Initially, energy-efficient clustering was achieved through an improved animal migration optimization scheme. Afterward, various factors including energy utilization, received signal strength, mobility, and collaboration ratio were collected to calculate the cost of all nodes in clusters. The node with the highest cost was selected as the CH. The route was selected using an enhanced ant colony optimization algorithm. However, it increases the CPR and PLR as it fails to address the issue of maintaining connectivity in the event of link failures during data transfer.

Three-dimensional clustered overlay peer-to-peer protocol (3DCOP) was presented for MANETs [15]. The 3D clustered overlay formation is utilized over MANETs to keep the physical neighborhood connectivity data of overlay partitioning peers in high mobility scenarios. Additionally, an efficient new method for managing replicas was implemented. But the MED was not satisfied with the increase in node mobility. A stable path election for adaptive data transfer in MANETs [16], which finds the optimal least-distance routing path. This route was driven by

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queue storage, where the discrepancy in the data storage was controlled. The data was stored in a queue to improve data transmission efficiency. But the PLR remained high due to the lack of proper maintenance on the path.

A robust spatial gabriel graph (RS-GG)-based clustering method was introduced for an ad hoc network [17]. At first, both primary and secondary users were clustered depending on the graph theory. Then, the RS-GG was applied in each cluster to determine the adjacent nodes by predicting the weighted MED. If the multi-route decision-making criteria were fulfilled, then the route was created for data transfer. But it does not consider link failures, which impact the CPR and PLR.

An adaptive mobility-aware clustering (AMAC) method [18] was presented to ensure reliability and network lifetime in MANET. First, nodes were clustered and CHs such as inter-CH and intra-CH were chosen by the hybrid artificial bee colony with particle swarm optimization (ABC-PSO). Also, the node mobility was estimated and the near next position was detected to choose the inter-CH for data transfer. But the link failure was not prevented, which caused high PLR, CPR, and MED.

From these recent studies, it can be addressed that those algorithms are unable to effectively handle the link failures in the routing path during data transfer. This causes high PLR and MED since the path reconstruction or alternative path discovery process takes a longer time. To address this challenge, the study utilizes the LFP strategy and the path discovery phase to predict link failures in the route and identify the most reliable shortest path for data transfer in MANETs.

3. Proposed methodology

This section briefly describes the GKCA-LFP for MANETs. Fig. 1 shows a conceptual design of the presented study.

Initially, the MANET is constructed and the graph of the MANET is built using graph kernel theory. The GKCA is used to determine the cluster size and select CHs through three main processes: subgraph creation, kernel determination, and kernel categorization [11]. The chosen CHs are then connected using the shortest path. This study utilizes the LFP strategy to predict the current link status and prevent link failures, ensuring reliable data transmission when determining the shortest path.

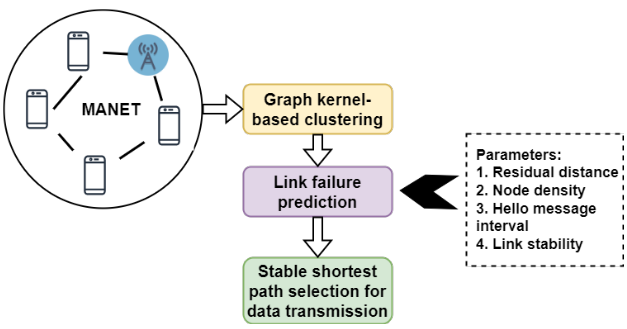

Figure. 1 Conceptual design of the presented study

3.1 Link failure prediction strategy

The LFP strategy is based on the principles of link expiry time (LET) and link stability (LS). This strategy considers factors such as mobility information, node density (ND), residual distance for the SN to exit the coverage area, and the frequency of Hello message exchanges to determine the likelihood of link failure. To maintain a stable connection between two nodes in the shortest (active) path between the SN and DN, the SN regularly evaluates the stability of the connection to the successive hop. This assessment is done at regular intervals based on the Hello message interval. The suggested LFP strategy includes pre-established threshold values and mobility data, such as the speed and direction of all nodes acquired via GPS. This strategy is activated while the connection to the successive hop node in a cluster is disrupted. Before the connection breakage, the DN forwards an acknowledgment packet (ACK) to the SN, which triggers a new path discovery procedure to find an alternative shortest path to the DN.

To develop a mathematical model for predicting link failure between nodes, i and j, the factors relevant to the LFP strategy are outlined in the subsequent parts.

3.1.1. Residual distance

The variable rd represents the residual distance, indicating the potential distance at which the successive hop node might exit the communication range of the SN. It is calculated using the location service, which provides information about the location of each node.

- The distance d between the successive hop node H in the current path and its parent node P is calculated by Eq. (1). Here, P is the node from which the data is received.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{1}$$

In Eq. (1), (x_1, x_2) and (y_1, y_2) are the coordinates of P and H, correspondingly, acquired by the GPS.

- The transmission range R of all nodes is calculated by the signal strength threshold and error probability denoted by bit error rate and considered to be 10^{-3}. So, the residual distance is computed by P as follows:

$$rd = R - d \tag{2}$$

- The residual distance must be computed at the point where the calculation of LFP is triggered while rd is less than rd_{th}. In this study, $rd_{th} = 0.75R$.

3.1.2. Hello message interval

Each node communicates with its 1-hop adjacent through a Hello message to modify mobility data, position coordinates, and the status of the neighboring node. In the network, all nodes using GKCA keeps an adjacent table that includes information about its immediate neighbors, such as their ID, position, and direction. These neighbors are divided into three groups based on their relative positions within the node's transfer range. The table is modified by forwarding a Hello message at specific periods. Considering that the SN will obtain the modified data regarding its adjacent nodes at the Hello message period (T), it is essential to take this into account for the LFP.

3.1.3. Node density (ND) in each cluster's transmission region

The ND is determined by splitting the amount of nodes by the size of the region or cluster. Each cluster contains a minimum of four nodes, one in each direction.

$$ND_{min} = \frac{4}{C_{region}} \tag{3}$$

In Eq. (3), ND_{min} denotes the minimum number of nodes (i.e., ND), and C_{region} refers to the cluster's transmission region. Therefore, the ND defines the percentage of the minimum amount of nodes that must be exist in the transmission region and the determined ND.

$$density_{ratio} = \frac{ND_{min}}{ND} = \frac{4}{N} \tag{4}$$

Generally, the ND value must increase if the amount of nodes in the transmission range increases and vice versa. To satisfy these criteria, the proportion of ND (F_{ND}) is defined by

$$F_{ND} = \begin{cases} 1 - \frac{4}{N}, & N > 4 \\ 0.2, & N = 4 \\ \frac{0.2}{4-N}, & Or\ else \end{cases} \tag{5}$$

3.1.4. Link stability

The LET is essential for calculating LS, which determines how long a link between 2 nodes can last without interruptions. LS and LET are taken as the primary factors in designing LFP strategy because they play a significant role in determining Link Life Time (LLT). The LET between nodes i and j is computed by

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \tag{6}$$

In Eq. (6), $a = v_i \cos\theta_i - v_j \cos\theta_j$; $b = x_i - x_j$; $c = v_i \sin\theta_i - v_j \sin\theta_j$; and $d = y_i - y_j$. Here, v_i, v_j are the speed of i and j, respectively, and θ_i, θ_j denote the traveling direction of i and j, correspondingly. Also, (x_i, y_i) and (x_j, y_j) indicate the coordinates of i and j, correspondingly.

3.2 LFP strategy

A mathematical framework is used to compute the LS and choose the optimal time for P to forward an ACK packet to the SN, using the factors mentioned earlier. Certain procedures and hypotheses are prepared to construct this framework. In the scenario where two interconnected nodes are traveling at an equal speed and in equal direction, the LET between them is considered to be infinite. In contrast, the worst-case situation happens when one node reaches the highest speed and another operates at the lowest speed and in opposite direction. In this case, the LET value is directly proportional to the LS between the nodes. The LS is provided by

$$LS = 1 - e^{\left(\frac{-LET}{\alpha}\right)} \tag{7}$$

In Eq. (7), α denotes a constant and its value is increased to maximize the LS and estimate the connection breakages. Therefore, this study modifies the LET by combining the above-mentioned factors to support in discovering LS and predicting link failure.

It is important for LET to consider the impact of a high T for Hello messages to prevent outdated statistics regarding the successive hop node. The LET is inversely related to T between Hello messages.

An increase in T may negatively impact the LET,

Algorithm 1: GKCA-LFP for MANETs

Input: N number of MANET nodes, Randomly created MANET graph G, predefined kernel matrices K, hop count h, variable λ, amount of clusters C

Output: Cluster size, CH nodes, and robust shortest paths

1. Initialize G;
2. $\boldsymbol{for}(i = 1{:}\, n)$
3. Apply GKCA algorithm as in [11] to determine the cluster size and CHs;
4. Calculate d between H on the current path and its P in Eq. (1);
5. Calculate the residual distance rd in Eq. (2);
6. Update the adjacent node table by broadcasting Hello messages at T;
7. Determine ND_{min} that must be available in the cluster in Eq. (3);
8. Calculate $density_{ratio}$ and F_{ND} in Eqns. (4) and (5), respectively;
9. Compute LET between i and j in Eq. (6);
10. Determine LS and F_{rd} in Eqns. (7) and (8), respectively;
11. Predict the link failure using Eq. (9);
12. $\boldsymbol{end\ for}$
13. **Return** the shortest path with more stable links.

while a decrease in T can enhance the LET. To effectively implement the concept of residual distance in the LFP strategy, certain conditions need to be addressed:

- Near the boundary of the coverage area, nodes are more likely to experience link failure due to a shorter residual distance.
- Maximizing the residual distance increases the probability of these nodes staying within range.

The proportion of the residual distance is calculated by

$$F_{rd} = \frac{rd}{rd_{th}} \tag{8}$$

This implies that nodes located further from the border will have a higher F_{rd} value, whereas nodes closer to the border will have a lower F_{rd} value. Moreover, Eq. (7) is reformulated for predicting link failure in the following manner:

$$LFP = 1 - e^{\left(\frac{F_{rd} \times LET \times F_{ND}}{\alpha \times T}\right)} \tag{9}$$

In Eq. (9), LFP stands for link failure prediction, and LET is calculated based on Eq. (7). It should be noted that the LFP value ranges $[0,1]$. Therefore, for P to notify the SN to commence a new path (i.e., shortest path) discovery process, the LFP must be less than the threshold value LFP_{th}. In this study, LFP_{th} value is designated as 0.5, signifying the central point within the range of LFP values.

The overall pseudocode for GKCA-LFP is provided in Algorithm 1.

The proposed GKCA-LFP ensures path maintenance to prevent link failures caused by the high-mobility nodes in MANETs within the transmission region. The flow diagram of GKCA-LFP is depicted in Fig. 2.

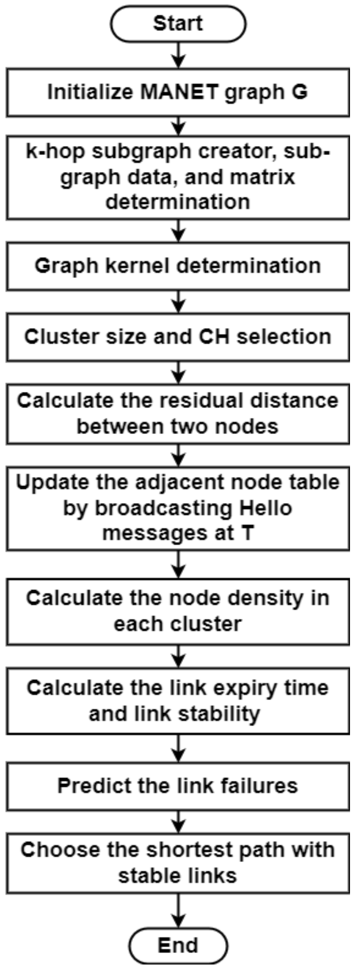

Figure. 2 Flow diagram of GKCA-LFP for MANETs

4. Simulation result

This section evaluates the GKCA-LFP algorithm's efficiency in comparison to existing algorithms such as the GKCA [11], MARP-HO [14], RS-GG [17], and AMAC [18].

4.1 Simulation setup

The essential codes for proposed and existing

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Table 1. Simulation parameters

Parameters	Values
No. of nodes	100
Node mobility	0 – 20 m/s
Simulation area	$1000 \times 1000\text{m}^2$
Queue length	50 packet
MAC layer	IEEE 802.11
Traffic class	Constant Bit Rate (CBR)
Packet size	512 bytes
Communication range	200 m
Mean node degree	3 – 5
Mobility model	Random way point
Propagation model	Free space
Channel bandwidth	2 Mbps
Carrier frequency	2.4 GHz
Initial energy	100 J
Transceiver energy	0.6 J
Receiver power	0.35 J
Node pause time	1 sec
Simulation period	150 sec
Routing protocol	GKCA-LFP, GKCA, MARP-HO, RS-GG, and AMAC

algorithms are simulated in the Network Simulator version 2.35 (NS2.35) in the Ubuntu environment. The simulations are performed in a laptop armed with an Intel ® Core TM i5-4210 CPU @ 2.80GHz, 4GB RAM, and a 1TB HDD running Windows 10 64-bit. Multiple simulation runs were conducted for each scenario execution, with varying parameter settings. The average data from these simulation runs was selected. The simulation parameters used to configure the network in all proposed and existing algorithms are listed in Table 1.

4.2 Performance evaluation measures

The performance evaluation measures considered for comparative analysis are defined as follows:

- CPR refers to the percentage of control packets generated by the CH to restore connectivity with the data packets created by the CH.
- PLR is the percentage of lost packets transmitted from the SN to the DN, compared to the sum quantity of packets transmitted.
- MED is the mean interval that the packets take to travel from their SN to the DN.

The performance analysis investigates two scenarios: (i) Scenario 1: increasing the number of MANET nodes, and (ii) Scenario 2: increasing the mobility speed of nodes.

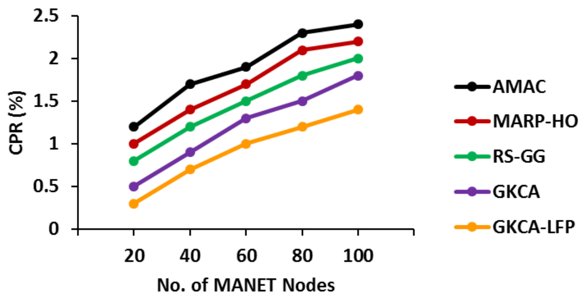

Figure. 3 CPR vs. No. of nodes

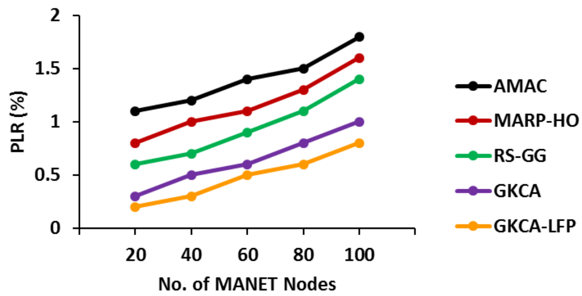

Figure. 4 PLR vs. No. of nodes

4.3 Performance analysis for scenario 1

In this scenario, the number of MANET nodes is increased from 1 to 100, with a constant mobility speed of 0 m/s.

A comparison of proposed and existing clustering algorithms in terms of CPR is shown in Fig. 3. If the node counts increase, the quantity of control packets also increases, increasing CPR. Through this graph, it can be observed that the CPR of GKCA-LFP is reduced than that of AMAC, MARP-HO, RS-GG, and GKCA because of selecting robust CHs and shortest paths for data transmission. If there are 100 nodes, the CPR of GKCA-LFP is reduced by 41.67%, 36.36%, 30%, and 22.22% compared to AMAC, MARP-HO, RS-GG, and GKCA, respectively.

Fig. 4 portrays a comparison of proposed and existing clustering algorithms in terms of PLR. When the node count is low, then the PLR of GKCA-LFP is very low, compared to the other existing algorithms. If the node counts increase progressively, then the PLR as well increases regularly; but the PLR of GKCA-LFP doesn't high considerably owing to avoiding link failures and selecting robust shortest paths, ensuring minimum PLR during data transmission. If there are 100 nodes, the PLR of GKCA-LFP is reduced by 55.56%, 50%, 42.86%, and 20% compared to AMAC, MARP-HO, RS-GG, and GKCA, respectively.

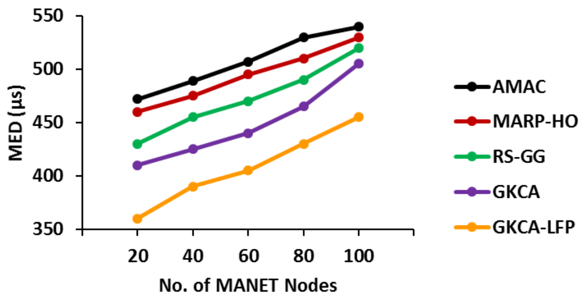

Figure. 5 MED vs. No. of nodes

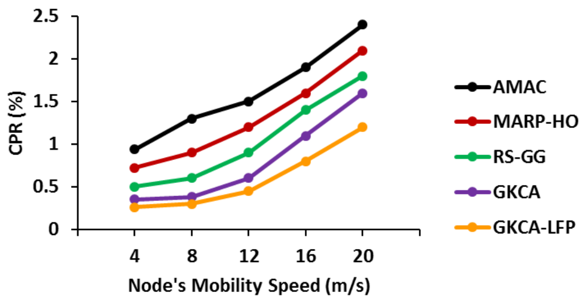

Figure. 6 CPR vs. mobility speed

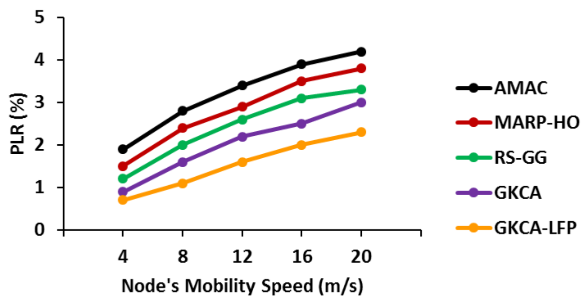

Figure. 7 PLR vs. mobility speed

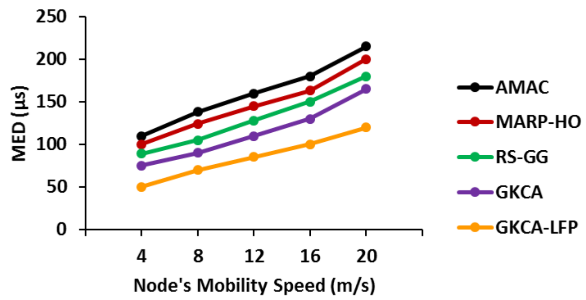

Figure. 8 MED vs. mobility speed

Fig. 5 compares proposed and existing clustering algorithms in terms of MED. With the increasing node counts, the GKCA-LFP is superior to that of existing algorithms. The plot demonstrates that the MED of GKCA-LFP is lower than AMAC, MARP-HO, RS-GG, and GKCA by 15.74%, 14.15%, 12.5%, and 9.9% respectively, with a network size of 100 nodes. The GKCA-LFP algorithm ensures minimum MED and PLR by preventing link failures and determining robust shortest paths with stable links for data transmission.

4.4 Performance analysis for scenario 2

In this scenario, the mobility speed of 100 nodes is increased from 0 to 20 m/s.

Fig. 6 compares proposed and existing clustering algorithms in terms of CPR. The GKCA-LFP algorithm can predict link failures with increased node mobility speed, requiring fewer modifications in clustering and CH selection and fewer control packets compared to other existing algorithms. Therefore, the CPR of GKCA-LFP is lower than that of existing algorithms. If the node's mobility speed is 20 m/s, the CPR of GKCA-LFP is reduced by 50%, 42.86%, 33.33%, and 25% compared to AMAC, MARP-HO, RS-GG, and GKCA, respectively.

In Fig. 7, a comparison of proposed and existing clustering algorithms is shown in terms of PLR. It can be observed that increasing the mobility speed of nodes can minimize the PLR. This can be achieved by predicting link failures using the GKCA-LFP algorithm, resulting in a lower PLR compared to other algorithms. The PLR of GKCA-LFP decreases by 45.24%, 39.47%, 30.3%, and 23.33% compared to AMAC, MARP-HO, RS-GG, and GKCA, respectively, when the node's mobility speed is 20 m/s.

Fig. 8 compares the MED for proposed and existing clustering algorithms. It is evident that as the node mobility speed increases, the MED also increases gradually. However, the GKCA-LFP algorithm outperforms others by accurately predicting link failures and selecting the shortest path with stable links for efficient data transmission. The MED of GKCA-LFP decreases by 44.19%, 40%, 33.33%, and 27.27% compared to AMAC, MARP-HO, RS-GG, and GKCA, respectively, if the node's mobility speed is 20 m/s.

5. Conclusion

The study presents the GKCA-LFP for MANETs, which aims to prevent path failures caused by node mobility during path discovery and data transmission. The GKCA algorithm determines cluster size and CH nodes and then utilizes the shortest route for data transfer. The LFP strategy predicts link status by using mobility and position information to maintain the path. The experiments used the NS2.35 tool to evaluate performance in two scenarios. The results demonstrated that the GKCA-LFP algorithm outperforms existing algorithms by effectively preventing link failures and selecting the shortest paths with more stable links. The results of Scenario 1, which included 100 nodes, demonstrated that the

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GKCA-LFP achieved a CPR of 1.4%, a PLR of 0.8%, and a MED of 455μs. In Scenario 2, with a mobility speed of 20m/s, the GKCA-LFP achieved a CPR of 1.2%, a PLR of 2.3%, and a MED of 120μs. On the other hand, future research could investigate the energy consumption of individual nodes in the network and develop a clustering algorithm that prioritizes energy efficiency. This would help prolong the lifespan of the network.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

Conceptualization, methodology, software, validation, Gayathiri; formal analysis, investigation, Mohanapriya; resources, data curation, writing—original draft preparation, Gayathiri; writing—review and editing, Gayathiri; visualization, supervision, Mohanapriya.

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