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Performance Evaluation of a Multi-Hop Cluster Based Algorithm for Vehicular Ad-hoc Networks

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Abstract: Vehicular ad hoc networks are characterized as the ad hoc networks with dynamic and dense network topology which faces issues like routing, data congestion, and overhead. One technique which has proved to be useful in managing VANETs is clustering. Clustering is a technique to divide the network into smaller, distributed and more stable hierarchical structure. The parameters like speed, position, distance, direction and mobility are used for clustering the networks. Clustering helps in load balancing, improving scalability, efficient resource allocation and reducing overhead. In this paper a multi-hop cluster-based algorithm (MhCA) for VANET is proposed which uses Fuzzy TOPSIS for CH selection based on Rank Index of nodes. The flowchart of the algorithm along with the description of the algorithm is given below in the paper. Extensive simulation experiments are run using the ns3 and SUMO to evaluate & compare the performance of proposed algorithm with the existing multi-hop algorithms like VMaSC and n-hop.
Keywords: CH, CM, CH Change Duration, CH Duration, OSM, NS3.

I. INTRODUCTION

Vehicular Ad-hoc Network commonly known as VANET is a kind of ad-hoc network that consists of vehicles as nodes. These nodes communicate with each other and the surrounding infrastructure using the on-board units and road-side units designed for this purpose. VANET is among the top researched area of ad-hoc networks due to the number of applications it provides. The major category of applications includes information exchange, internet access, real time video and audio downloads real time road and traffic monitoring, emergency braking, traffic jam management, efficient fuel usage and accident prevention [1] [14]. VANETs are characterized by characteristics like high mobility leading to dynamic topology, high scalability requirements, limited roadside units, unlimited battery power and storage, mobility modeling and prediction, decentralized self-organizing network [2] [15].

In VANET the major concern is its highly dynamic topology which can be handled by forming a smaller distributed network. Clustering is one such technique which helps in forming a distributed hierarchical network out of a large dense network. Clustering can be defined as a technique to group the nodes of a network to form a distributed network where the grouping is done on the basis of various metrics such as location, relative speed, velocity, density, link connectivity, expected transmission time [3]. The clusters thus formed consist of different category of nodes like Cluster Head, Cluster Member, Secondary Cluster Head and Gateway Node and each node of a cluster must fall in one of the category. The major factors which decides the performance of clustering is: selection of CH, type of cluster model, logic used for cluster formation. The cluster model can be of two types. Single-hop clusters where the CM is always directly connected to the CH, the CM is one node away from CH and multi-hop clusters where the CM may or may not be directly connected to the CH. The CM can be connected to the CH using another CM node(s) in between. Each single-hop and multi-hop networks have pros and cons of their own. There are number of CH selection strategies available in the literature of VANET. Clustering has been proved to be a beneficial technique in handling issues like routing, network management, traffic in data propagation, efficient resource consumption/ allocation with low overhead, improving routing scalability and reliability in VANETs, improving the scalability of the large scale VANET, load balancing, and target tracking [4]. Here in this paper we have proposed a multi-hop cluster based algorithm where the CM can be three hops away from the CH. The CH selection technique used is a rank based technique which uses Fuzzy TOPSIS to find the rank index of the nodes of a network. To the best of our knowledge this is among the first schemes where fuzzy TOPSIS is used for calculating the rank index of a multi-hop cluster based VANET architecture. Section 2 gives the literature review for the use of clustering in VANET. A table is given which shows the features of various researches in order of their occurrence along with the parameters and logic used for CH selection. In section 3 proposed model is given. Section 4 gives the simulation results of comparison of the proposed model with the two much discussed multi-hop clustering model for VANET i.e. VMaSC and N-hop. Three parameters are used for the evaluation of the algorithms; these are the most used stability performance metrics in the literature of VANETs [9]. The last Section 5 concludes the paper.

II. RELATED WORK

In this section, literature review is given in tabular form which presents the work done by various researchers in the area of clustering in VANETs. The table gives the names of the researcher and the work done by them. It also gives the list of parameters used for the CH selection. The table also presents the type of cluster model designed and the features in each case. Clustering logic is also given in the table which tells how clusters are designed. From the literature, it is evident that the use of clustering has proved to be beneficial for VANETs in various manners [5] [17].

Table I: Clustering algorithms used for VANET

Author & Year of Publication	CH selection parameters	Clustering logic	Features
S. Basagni [4](1999)	Mobility, size of the network	Weight-based on different parameters like connectivity, mobility, or energy level.	Single-hop model. Efficient partitioning of the nodes of an ad hoc network. Medium stability is provided
S. Kuklinski et al. [6](2009)	Link quality, traffic conditions, connectivity level.	Clustered and un-clustered node-based Multi-criteria clustering. Link quality clustering decision.	Single-hop model. Stability has increased significantly when compared to the previously defined algorithms.
Z. Zhang et al. [7](2011)	Packet delivery delay-based relative mobility, signal strength	Smallest aggregate mobility device selected as CH	Multi-hop model. Improved stability & reduced overhead.
L. Zhang et al. [8](2012)	Relative mobility based on aggregate mobility	Packet transmission delay based relative mobility	Multi-hop model. Improved scalability, reduced topology discovery cost & reduced effect of mobility on control overhead
Seyhan Ucar et al. [9] (2013)	Least mobility based on relative speed.	Least mobility calculation based on the speed difference between neighboring nodes of the same direction.	Multi-hop model. High CH and CM duration & low CH change duration when compared to similar type algorithms.
Y. Chen et al. [10](2015)	Average relative mobility which helps in neighborhood follow technique between vehicles	Neighborhood follow method which assumes that vehicle can easily identify the most stable vehicle in its one-hop distance thus, most likely to form a cluster.	Multi-hop model. Improved stability. Used for highly dynamic traffic scenarios.
Farhan Aadil et al. [18](2016)	Direction, speed, the load balancing factor	Node probability based ant colony optimization	Gives the best performance when compared to other swarm optimization techniques under varying road conditions & transmission range.
M. Ren et al. [11](2017)	Back off-based cluster head selection	Vehicle relative position, relative velocity & link lifetime metrics used for mobility-based clustering.	Consists of neighbor sampling, and cluster maintenance based on backup CH. High cluster stability.
D. Zhang et al. [12](2018)	Link lifetime, expected transmission counts, node following degree based on position and velocity.	Priority-based neighbor following to select optimal neighbor nodes.	High stability and reliability among inter-cluster nodes. Cluster merging is used for cluster maintenance. High robustness.
Alsuhli et al. [13] (2019)	Relative position & speed, average SNR, average link expiration time, popularity.	Mobility-based clustering.	Double head clustering with all-member-interest-based merging & cluster replacement. Increased cluster stability & efficiency.
Abubakar Bello Tambawal et al. [16] (2019)	Mean speed & distance, node connectivity level	Weight based on mean speed, mean distance, and node connectivity level.	Single hop model. Improved stability & reduced delay also use of secondary CH concept.

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III. PROPOSED MODEL

The proposed multi-hop model is a cluster-based model in which periodic Hello and CHHello messages are exchanged between the vehicle nodes. In this multi-hop model, the CH and CM nodes can be 1-hop or multi-hop away from each other. In the proposed model, a double cluster head concept is used where two CH nodes are available and in case of failure of the original CH, another subordinate node acts as CH which is kept as a backup of CH. The selection of CH and CSN is done, on the basis of the rank index which is calculated using Fuzzy TOPSIS (Technique for order of preference by similarity to ideal solution) where the highest rank node is selected as CH and node with the next highest rank (but less than CH) is selected as a CSN. All the vehicle nodes can switch between various states while custering which are defined below:

1) *IN*- Initial State. It is the first state assigned to a vehicle as it enters the network.
2) *UC*- Unclustered Vehicle. This state is assigned to the vehicles before the start of the clustering process.
3) *CH*- Cluster Head state. This state is assigned to a vehicle when its rank index is found to be the highest in the cluster and then it is selected as a CH.
4) *CSN*- Cluster Subordinate node state. This state is assigned to a vehicle when it is selected as a subordinate node in the cluster.
5) *CM*- Cluster Member state. This state is assigned when a vehicle attaches itself to an existing cluster where some CH is already present making the present vehicle a cluster member.
6) *ISO-CH*- Isolated cluster head state. This state is assigned to a vehicle when it is an isolated vehicle which means it doesn't have any neighbor vehicle nor does it can join any cluster.

In this proposed model a stability list is designed using link duration [19] using which neighbor sampling is done.

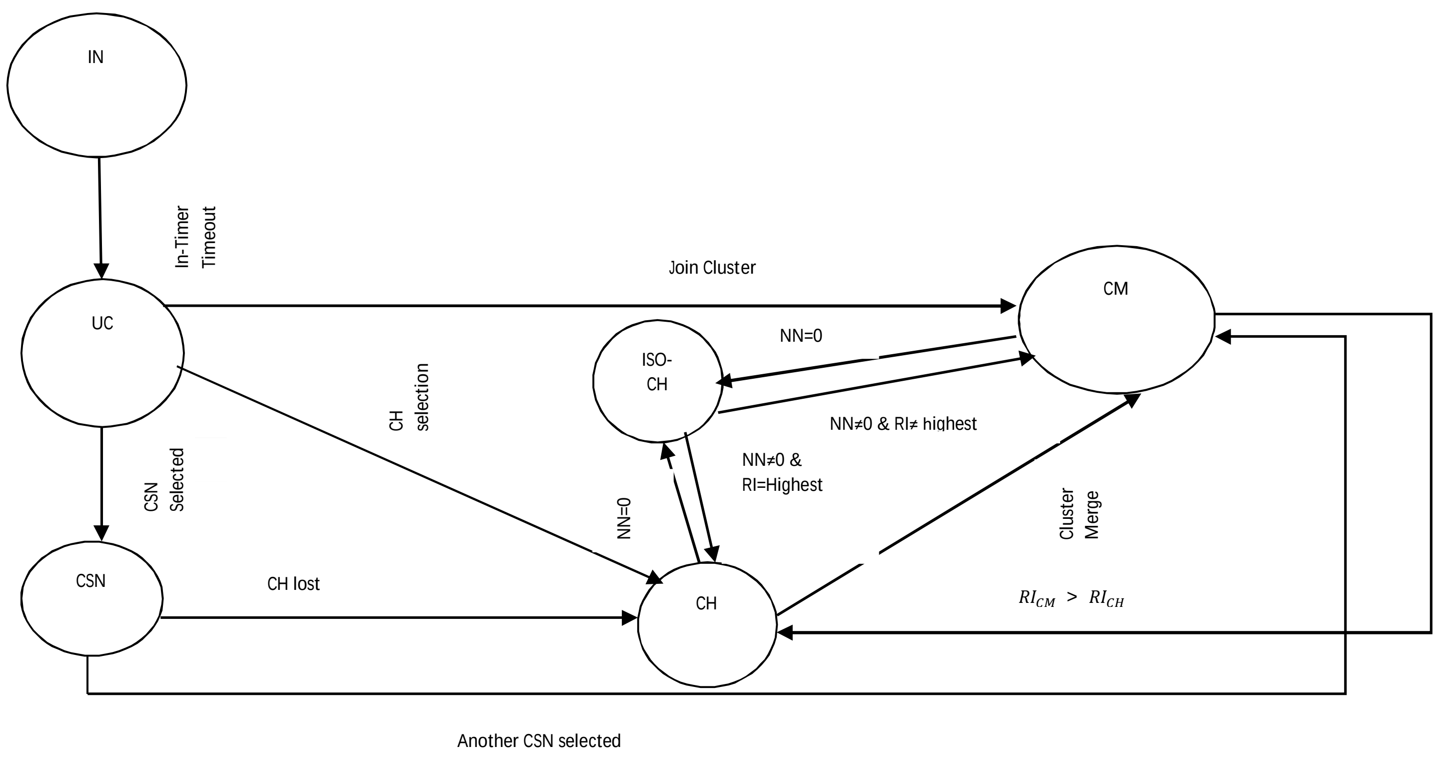


Figure I Vehicle States

Link Duration (LD) represents the predicted duration for which two vehicle nodes will remain connected with each other.

$$LD_{ij} = \frac{|\Delta V_{ij}|.CR - \Delta V_{ij}.\Delta D_{ij}}{(\Delta V_{ij})^2} \qquad (1)$$

Where ΔV_{ij} & ΔD_{ij} represents the difference of velocity & distance between V_i & V_j respectively.
CR- transmission range of the vehicle.

After designing the stability list, each node will decide the best node to follow using the degree based neighbor following strategy [6] where the node following degree of each vehicle is calculated as per formula given below:

$$N_{follow} = D_{neigh} + F_c \qquad (2)$$

Where D_{neigh}- number of neighbor nodes on the same lane

F_c- the number of connected nodes.

The node with the highest value of $N_{follow}$is followed.

Any clustering process includes CH selection, cluster formation, and cluster maintenance tasks. The CH selection for this algorithm is done using the Fuzzy TOPSIS technique on the basis of four parameters i.e. node connectivity level, relative mobility of vehicle, link quality estimation, mean distance. These parameters are further used as criteria for RI calculation.

Node connectivity level of a node is calculated as:

$$N_i(\mathrm{t}) = \sum_{j=1}^{n} dist(i, j, t) < Tx\ range \qquad (3)$$

Where j is neighbor of vehicle i, dist(i,j,t) is true if the connection between two vehicles i & j exist at time t otherwise it is false.

“Relative mobility of vehicle is calculated as an average of the relative speed of vehicles in the same direction[9].

$$X = \frac{\sum_{j=1}^{n} \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{N_i(t)} \qquad (6)$$

Where j is any neighboring vehicle that is connected to the vehicle i. N_i (t) is the total number of vehicles that are directly connected to vehicle i at time t. The Normalized mean distance $d_{normal} = \frac{n_{p-\mu_d}}{\sigma_d}$, where σ_d represents the standard deviation.

As the vehicle (node) enters the network it will receive periodic Hello or CHHello messages which consist of all the necessary information about the neighboring node. In the beginning, the vehicles are in IN state and remain in that state till the In-timer expires after which it enters the UC state.

Each time a vehicle receives a message it will check whether the message received is from a single node or multiple nodes. If the message is received from multiple nodes, a degree-based neighbor following strategy will be used to decide which specific node is to be considered for further communication.

A stable neighbor table will be designed to list the stable nodes present in the neighborhood using the stable Link Duration based strategy. After this, the state of the nodes in the stable neighbor table is checked to find if any CH/CM is already present in the neighborhood and there is no need for calling the CH selection procedure. If no CH/CM is found, then a node in the UC state will calculate its Rank Index and after the calculation of Rank Index using the Fuzzy TOPSIS technique using the above mentioned four parameters, CH and CSN are selected. The vehicle which has the highest RI among the neighbors will be selected as the CH. The vehicle can attain a CSN state if its rank index is less than CH but more than all the remaining vehicles. If the vehicle is not CH or CSN state it will be in CM state.

Rank Index Calculation using Fuzzy TOPSIS (Technique for order of preference by similarity to ideal solution)

The calculation of rank index using the Fuzzy TOPSIS technique includes the following steps:

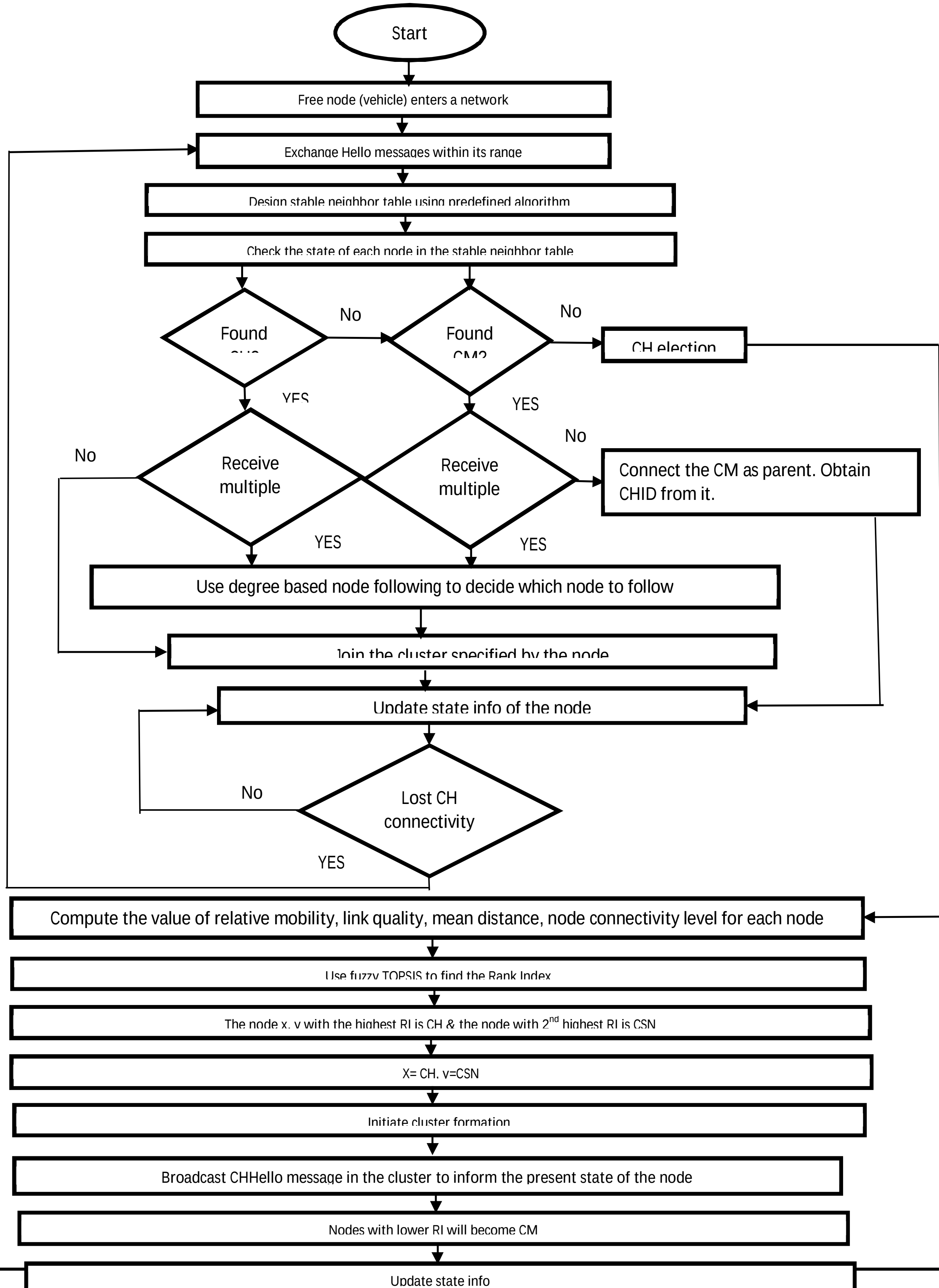
a) The first step is the categorization of the above-defined four parameters into positive criteria/positive ideal solution and negative criteria/ negative ideal solution. Here two criteria’s relative mobility and mean distance are considered as negative criteria whereas node connectivity level and link quality estimation are considered as positive criteria. After categorization, normalization of these positive criteria and negative criteria is done.
b) The next step then is to assign the weights to each of the criteria.
c) In this step, a Fuzzy membership function is defined. After this, the categorization of above defined normalized values and their weights for each node is done.
d) The next step then is designing a weighted decision matrix for each criterion and their respective weights.
e) Then the weighted decision matrix designed above is used for the calculation of the positive ideal solution and negative ideal solution.
f) In this step, the Calculation of separation measure from the weighted decision matrix is done.
g) In the last step, the calculation of the Rank Index using the given formula is done:

$$\text{R.I}= \frac{D_j^-}{D_j^+ + D_j^-} \qquad (7)$$

After getting the value of RI for each node CH and CSN are selected.

The complete flowchart defining the procedure of the proposed algorithm is given below in figure II.

Figure II. Flowchart of the Algorithm



IV. SIMULATION & RESULTS

The proposed model is simulated using the network simulator ns-3.30.1[20]. The proposed model is evaluated using three performance metrics under varying transmission and velocity scenarios. The results thus obtained are compared with the two well known multi-hop clustering models i.e. Vehicular Multi-hop algorithm for Stable Clustering (VMaSC) and N-hop in different hop scenarios. We have used VMaSC 1-hop, VMaSC multi-hop, N-hop (3-hop), Fuzzy Topsis (F topsis 1-hop and F topsis multi-hop) for comparison. Further details about the simulation values are given below in the tabular form.

Table II. Simulation Parameters

Parameter	Value
Simulation Time	100s
Simulation Area	1500*1500
Maximum velocity	50m/s
Transmission range	100-300m
Number of vehicles	250
MAC protocol	CSMA/CA
Channel Bandwidth	2048bps
Max-CM	4
CHHello packet size	64bytes
Hello-packet period	200m/s
Hello-packet size	64bytes
In-timer	2s
CH-timer	2s
Join-timer	2s
Merge-Timer	2s

The most commonly used stability metrics i.e. average CH duration, average CM duration, and average CH change duration are used for performance evaluation.

1) *Average Cluster Member Duration:* It is defined as the average time for which a vehicle remains in CM state and is a measure of a cluster member's lifetime. It includes the time from when a node takes the CM state and until it is transferred to another state. Given in Figure III is the comparison result of the three algorithms in transmission range 100m, 200m, and 300m respectively. The average cluster member duration of the proposed algorithm initially decreases with an increase in vehicle velocity and then increases and later becomes constant. This can be explained by state change scenarios. In the beginning, during low velocity, the vehicles have just entered the network. They have either advertised themselves as the CH or they are in the CH selection stage but after some time as the velocity increases the clusters are designed and the vehicles attain either CH state (in that case another CM attaches to it) or CM state. So in both cases the CM duration initially decreases. But as the velocity increases more and more stable clusters are designed, and the CM duration increases and becomes kind of stable as vehicles have already attained the CM state. Maximum hops between CH and CM is another factor that plays important role in deciding the value of average member duration. With the increase in the Maxhop value, the CM duration also increases for the proposed algorithm which means in the 1-hop scenario CM duration is less as compared to CM duration in the multihop scenario. The proposed Fuzzy TOPSIS algorithm, when compared to VMaSC, shows an almost 20% increase in the average CM duration in the 1-hop scenario and around a 5% increase when compared in the 3-hop scenario. When compared to n-hop algorithm, the proposed algorithm shows around a 25% increase.

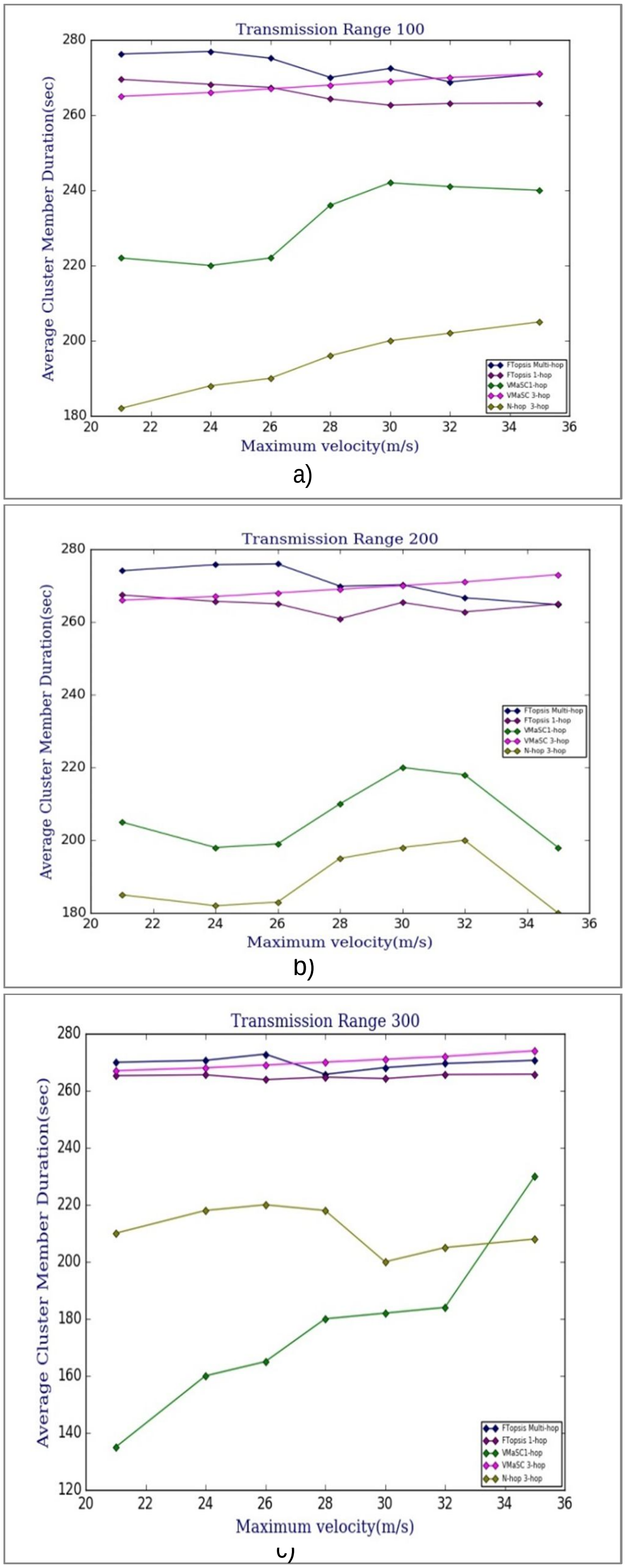


Figure III. Average CM duration in a) 100m b) 200m c) 300m transmission ranges

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2) *Average Cluster head Duration:* The average time duration for which the vehicle has attained the CH state is defined as average CH duration. It is also considered as the cluster head's lifetime. It includes the time from becoming a CH to the time till transferring to another state.

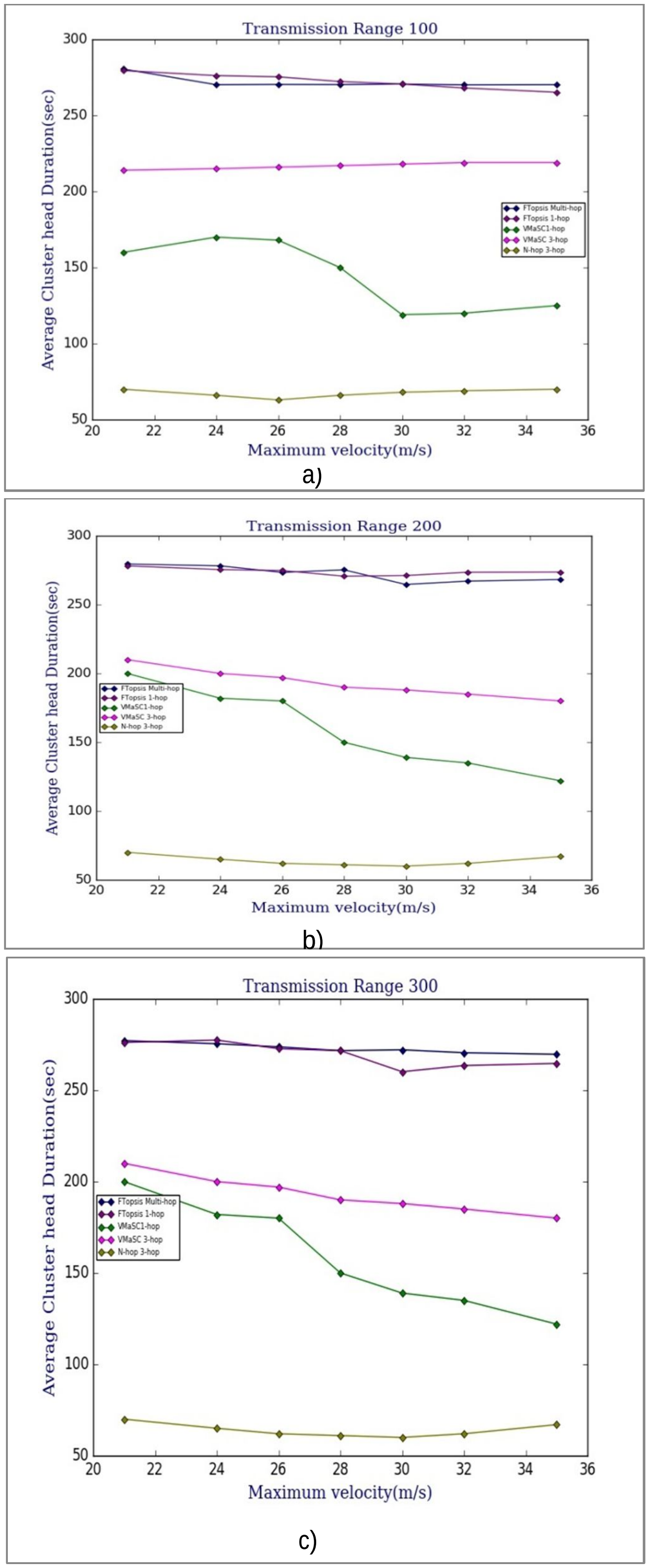

Figure IV Average CH duration in a) 100m b) 200m c) 300m transmission ranges

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The comparative result for the Average CH duration of the proposed algorithm with the two other algorithms in different transmission ranges and velocities is given in Figure IV. From the figure, it can be observed that for the proposed algorithm the average CH duration slightly increases with an increase in transmission range and decreases with an increase in velocity. This can be explained as: when the velocity increases the network topology becomes more dynamic which leads to calling of CH selection frequently further leading to a decrease in average CH duration. Moreover, as the transmission range increases the chances of an increase in cluster lifetime are there which can further help in increasing the average CH duration. Another factor that affects the CH duration is Maxhop, as the Maxhop value increases the average CH duration also increases. From the graphs, it can be analyzed that the average CH duration in single-hop scenario is somewhere similar or slightly increased to that in multi-hop scenario for the proposed algorithm. The proposed algorithm when compared with VMaSC algorithm gives approximately 40% increase in average CH duration in 1-hop scenario and around 25% increase in multi-hop scenario. The proposed algorithm also outperforms the n-hop clustering algorithm.

3) *Average Cluster Head Change Duration:* It is the metric to measure the cluster stability and is defined as the count of state change from CH state to another state. Figure V gives the graphical representation of the performance of the proposed algorithm compared to VMaSC and n-hop in terms of average CH change duration.

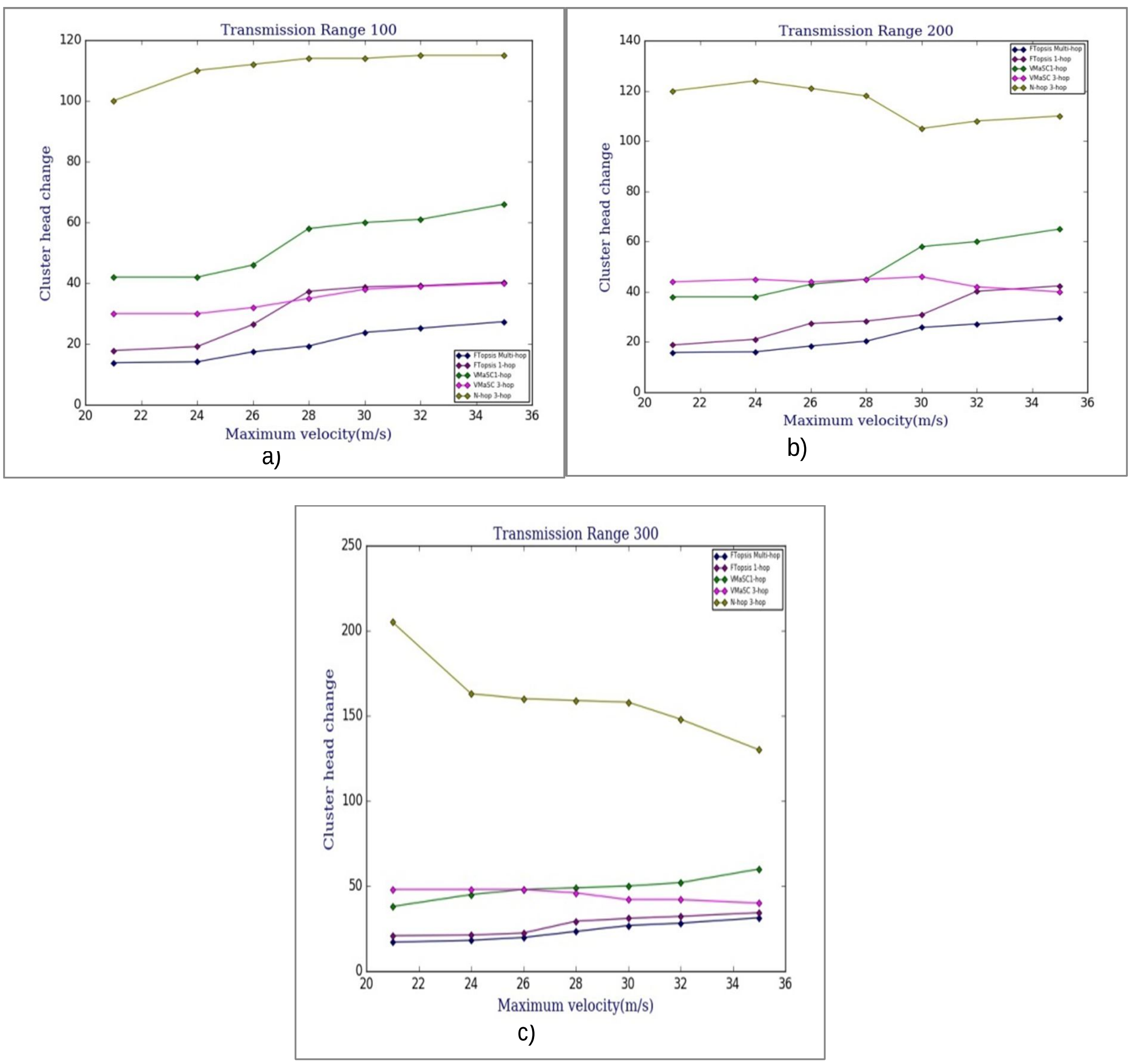

Figure V Average CH change duration in a) 100m b) 200m c) 300m transmission ranges

The average CH change increases as the velocity increases since the network becomes more dynamic with an increase in velocity leading to high changes in the state of a cluster. Due to this CH election process may start and the CH's may be selected again. Another factor that affects the average CH change duration is the transmission range. As the transmission range increases the average CH change increases in 1-hop as well as the multi-hop scenarios. For low transmission range the average CH change for the multi-hop scenario is 5% less compared to the 1-hop scenario but as the transmission range increases the average CH change in multi-hop and 1-hop scenario becomes almost the same. The reason behind this increase may be the collision of packets which may lead to the CH election process for a particular node. The proposed algorithm, when compared with VMaSC 1-hop, shows an almost 46% decrease in the 1-hop scenario and an almost 42% decrease in the multi-hop scenario. The proposed algorithm also outperformed the n-hop algorithm in terms of CHC duration.

V. DISCUSSION AND CONCLUSION

In this study, a new Fuzzy TOPSIS based CH selection algorithm is proposed for vehicular ad-hoc networks. This algorithm uses four metrics i.e. relative speed, expected transmission time, mean distance, and node connectivity level for calculating the Rank Index using the concept of fuzzy technique for order of preference by similarity to ideal solution. In the proposed algorithm a Double head concept is used where CSN and CH two heads are present and if one fails another takes its place thus reducing the need for re-clustering.

The proposed model is evaluated under different transmission ranges and velocities using three parameters i.e. average CH duration, average CM duration, and average CH change duration. It is simulated using the ns-3 simulator and from the simulation results explained above, it can be concluded that the proposed Fuzzy TOPSIS algorithm outperforms the previously proposed multi-hop algorithms i.e. VMaSC and N-hop algorithm in terms of average CH duration, average CM duration, and average CHC duration. The proposed algorithm is implemented in two versions 1-hop and multi-hop and in both versions, it outperforms the previously implemented algorithms. The main reason behind this improvement is the use of 4 input metrics (parameters) for the CH election using the Fuzzy TOPSIS technique. From the results, it can be further concluded that the use of fuzzy TOPSIS in CH election process proves to be beneficial if the criteria (parameters) are selected efficiently.

As a future enhancement, the algorithm can be modified to use different input metrics for the calculation of the Rank Index using the FUZZY TOPSIS technique. The effects of changing the input criteria metrics can be analyzed by comparing the results with the present algorithm. Also, the transmission range and velocity can be changed during the simulation process in order to further enhance the work. As a future enhancement of the work, we are planning to implement this algorithm to handle the handover issue in vehicular ad-hoc networks and analyze its effect on the handover process.

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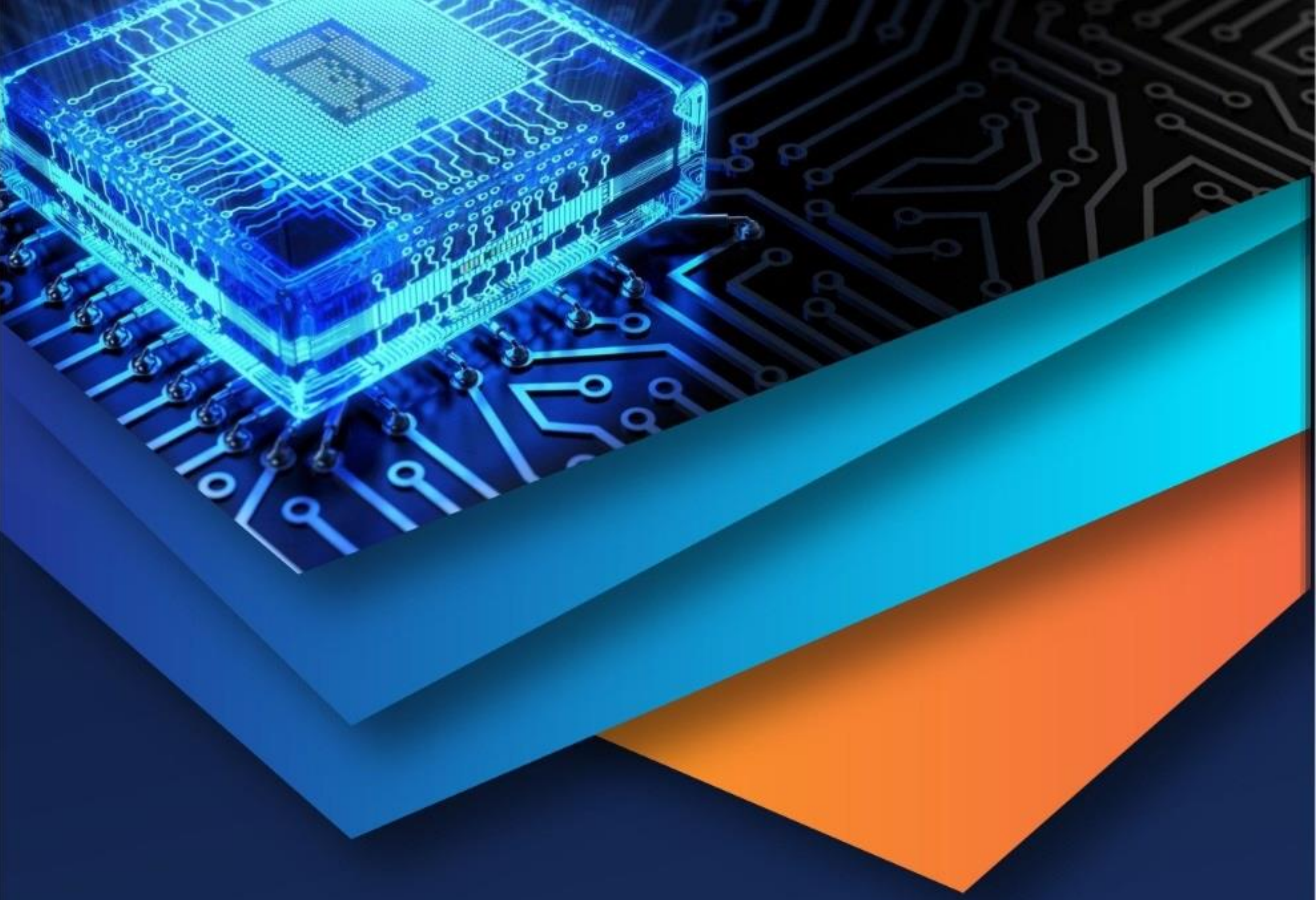

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