An Efficient Hierarchical Mechanism for Handling Network Partitioning Over Mobile Ad Hoc Networks

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***Abstract*—Mobile ad hoc networks exhibit distinctive challenges e.g., limited transmission range and dynamic mobility of the participating nodes. These challenges serve as the reasons for the frequent occurrence of network partitioning in mobile ad hoc networks. Network partitioning happens when a linked network topology is partitioned into two or more independent partitions. Because of this phenomenon, the participating node in one partition maintains no linkage with a node in another partition. Network partitioning results in the inaccessibility of mapping knowledge, logical labeling space, and logical structure of the participating nodes. As a result, the performance of a distributed hash tables (DHTs)-oriented routing mechanism is severely affected. In DHT-oriented routing methodologies, the logical network identifier of a new participating node is calculated by considering the logical network identifiers of all the physical neighboring nodes. The logical network identifiers are utilized for routing of packets from a source participating node to a destination participating node in the network. In the event of network partitioning, the incorrect computation of logical network identifiers happens concerning the physical proximity of the participating nodes. This research work suggests an effective routing mechanism to deal with the aforementioned network partitioning-related issues. Simulation results prove the superiority of the suggested scheme over the existing mechanisms.**

***Keywords*—Mobile Ad Hoc networks; network partitioning; distributed hash tables; logical cluster member node; logical cluster leader; logical network identifier**

I. INTRODUCTION

In mobile ad hoc networks (MANETs), there are two fundamental issues [1-4]. One of the issues is the restricted transmitting range. Another issue is the dynamic mobility of the participating nodes. Due to the identified issues, merging and partitioning of network architecture occur in mobile ad hoc networks. In the partitioning of a network, the linked structure is partitioned into two or more independent isolated segments [5-6]. Because of this phenomenon, the participating node in a segment has no contact with a participating node in another segment. On the other hand, the merging of network topology involves the integration of more than two independent partitioned segments [7-13]. This phenomenon occurs when the nodes in one independent partition start receiving hello messages from nodes of another isolated partition. It infers that the nodes in two independent partitioned networks lies in the identical transmitting range.

In DHT-based routing mechanisms, arrangement of the participating nodes is done considering the exploited logical identifier structure like chord, ring, or tree shapes [14-17]. In these topologies (chord, ring, or tree), there are restrictions on the number of routing paths. Some of the exploited topologies, the logical identifier space exhibit exclusively single routing path among the participating nodes. Consequently, these exploited topologies experience minimal resilience in choosing another routing path. In multi-dimensional DHT-based routing mechanisms, high resilience is observed during the selection of alternate routing paths. In mobile ad hoc networks (MANETs), there is a higher possibility that the logical identifier structure is partitioned. The partitioning of the logical identifier is dependent on the construction exploited by the logical identifier space. Hence, an effective logical identifier structure offers resilience related to the adaptation of routing paths when forwarding the data packets. It infers that there are alternate routing paths available in case of participating node failure or mobility. This type of construction is independent of redundant routing paths towards the destination. The reason is that exploited construction offers alternative routing paths (typically more than one) towards the destination participating node in the logical identifier space. In case a node is not available due to the partitioning of the network, then an alternate routing path can be exploited to reach that destination node in the network. It means that multiple routing paths assist in maintaining availability to a participating node in the network. In addition, logical identifier structure is separated in case of merging of two or more physical networks. It is a serious issue to recognize the happening of network merging at the logical identifier structure after physical networks merging. In addition, the smooth merging of two or more logical networks after the detection of network merging is a big issue. Therefore, there is a need to develop a DHT-based routing mechanism that should address the network merging detection and the merging of logical networks afterwards.

As discussed in study [18-22], the process of disintegrating the linked network topology into more than two isolated networks is referred as partitioning of the network. In the existing DHT dependent routing mechanisms, typically the attention is on providing an efficient resolution to the mismatch issue [23-26]. All these DHT dependent routing schemes neglect a critical challenge that is partitioning of logical networks. The partitioning of the network is responsible for the disruption of connectivity among the sender and receiver participating nodes. Because of the network partitioning, the participating nodes are unable to contact each other in the isolated partitions. The reason for this inaccessibility is the disruption of communication among the participating nodes. There are several reasons for the occurrence of network partitioning in mobile ad hoc networks. In mobile ad hoc networks, the dynamic movement of the participating nodes, the self-organized character and the restricted transmission scope are mainly the reasons for the persistent isolation of linked networks. In DHT dependent routing mechanisms, network partition is the cause of diverse critical challenges. The critical challenges due to partitioning of the network consist of DHT construction decomposition, depletion of the logical identifier space and participating nodes' mapping information (MPI) unavailability. In DHT dependent routing mechanisms, these critical challenges have deteriorated influences. Because logical identifiers instead of universal identifiers (IP or MAC address) are exploited for interaction between the participating nodes. The accessibility of mapping information stored at the anchor node plays a critical role. Because it provides the logical identifier information of the receiver participating node in the logical network. In DHT dependent routing schemes over MANETs, effectiveness can be achieved by efficiently recognizing the critical links or nodes. These critical links or nodes are responsible for activating the isolation or partitioning of physical topology. Therefore, recognition of critical nodes or links should be done promptly. By doing so, information depletion is alleviated significantly. Additionally, interruption of connection is greatly minimized.

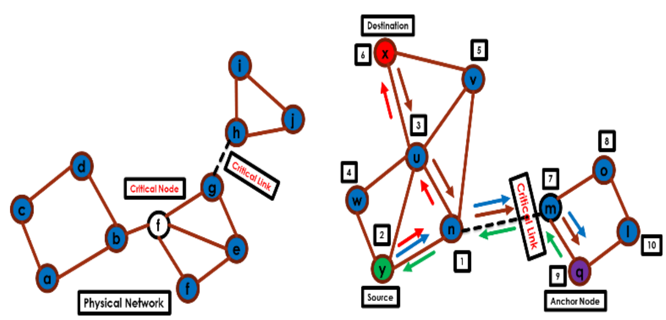
The critical link is a critical association in the logical network. If the critical link is unavailable, then partitioning of the network occurs. On the other hand, a critical participating node is a critical node in the logical network. If the critical participating node becomes unavailable, then partitioning of the network occurs. In the following Fig. 1(b), both the cases are well described. Recognition of critical links or nodes is efficiently done considering the prevalent neighboring participating nodes (x-hop) in a distributed manner.

To recognize the critical association and corresponding critical participating nodes in an efficiently distributed manner, mutual neighborhood connectivity information (x-hop) is exploited. In Fig. 1(b), n↔m association is perceived as a critical one (x-hop) in case the adjoining participating nodes of 'n' and 'm' are not in contact after the failure or breakage of the critical association. The association n↔m in Fig. 1(b) is considered one hop critical (x=1) in case neighborhood connectivity (one hop) is separated after failure or breakage of the critical association. The association n↔m is considered two hops critical (x=2) in case of unavailability of a mutual neighboring node among the neighborhood connectivity (two hops) of critical nodes 'n' and 'm'. This association is considered globally critical. The reason is the unavailability of a mutual neighboring node among the critical nodes 'n' and 'm'. For this purpose, consider x=3, 4 and so on. In the Fig. 1 (b), the node 'y' is considered as the critical participating node (globally). The reason is the separation of neighborhood connectivity of the participating node 'y' into two independent partitioned networks.

In the literature review [22-32], it is observed that research community relating to DHT-based routing does not highlight or elaborate the vital issues involving the partitioning of network. These critical issues should be effectively addressed by the research community. In this research work, a novel solution to address the crucial issues involving network partitioning is presented. It is called the 3DcPR (three-dimensional clustered partition detection with dynamic replication). This novel partition recognition strategy utilized the local neighborhood connectivity knowledge of every participating node in the 3D environment i.e., 3D logical identifier construction for efficient recognition of critical association in the physical topology. In addition, this strategy presents an efficient and dynamic solution for replication management. An efficient and dynamic replication methodology is considered beneficial to decrease the information dissipation and interruption of connection. Additionally, a novel retrieval methodology of misplaced logical identifier space is suggested. Due to the partitioning of network, the logical identifier space depletion phenomenon is observed. As far as we are aware, the suggested research work falls in the category of innovative ones in dealing with the partitioning of networks involving the DHT-based hierarchical routing protocol in mobile ad hoc networks (MANETs). This research shares the following remarkable innovations and advantages in comparison to the existing methodologies:

- We have delineated and instigated a novel partition detection and replication management mechanism termed as 3DcPR for working at the networking layer over MANETs.
- We have proposed a scheme for the identification of critical link and corresponding critical node. In this scheme, the local neighborhood knowledge of the participant nodes is utilized.
- We have suggested a replication management mechanism to smoothly establish and maintain the connectivity considering occurrence of the network partitioning over MANETs. This novel replication scheme significantly decreases the lookup latency.
- We have proposed a technique by integrating logical clustering along with DHTs to cope with the network partitioning scenarios in an effective manner.
- We have proposed an efficient technique that offers significant resilience against node failures or movements by utilizing the gateway nodes in the network.

The following tables (Table I and Table II) present the descriptions of key terms alongside their abbreviations being utilized in the current research work.



(a) (b)

Fig. 1. (a) Critical nodes and corresponding critical association, (b) Stocking and retrieval of mapping details before network partitioning.

TABLE I. ACRONYMS AND ABBREVIATIONS

Abbreviation	Description
BNT	Base Network Topology
LNT	Logical Network Topology
BNI	Base Network Identifier
LNI	Logical Network Identifier
LCL	Logical Cluster Leader
LCMN	Logical Cluster Member Node
LGPN	Logical Gateway Participating Node
MD	Mapping Details
LAPN	Logical Anchor Participating Node
MPTA	Mapping Petition Alarm
MRA	Mapping Reply Alarm
SCPN	Source Cluster Participating Node
DCPN	Destination Cluster Participating Node
DHTs	Distributed Hash Tables
MANETs	Mobile Ad Hoc Networks

TABLE II. DEFINITIONS OF IMPORTANT TERMINOLOGIES

Terminology	Definition
Base Network Topology	The physical neighborhood connection of the participating nodes.
Logical Network Topology	The logical network construction by utilizing the logical network identifiers of the participating nodes.
Logical Network Participating Node	The participating node in the logical network pattern on top of MANETs.
Base Network Identifier	The distinct identifier of logical network participating node in the physical network pattern.
Logical Network Identifier	The tag of the participating node in logical network pattern.
Logical Cluster Leader	It is the controller of the logical cluster in logical network pattern. It is selected by considering the highest participating node degree.
Logical Cluster Participating Node	It is the member node in a logical cluster.
Logical Anchor Participating Node	The participating node in the logical cluster which is responsible for stocking the mapping details of other participating nodes.
Logical Gateway Participating Node	It is participating node in logical cluster that comes under communication zones of more than one logical cluster leaders.

The rest of this paper is organized as follows: Section II presents the problem formulation with a detailed example scenario. Section III elaborates on the proposed novel mechanism for handling network partitioning on top of MANETs. In Section IV, the evaluation of the proposed mechanism is discussed. Ultimately, this research is wrapped up in Section IV alongside the future research directions.

II. PROBLEM FORMULATION

The disintegration of a linked topology into two or more isolated partitions is termed as network partitioning [33]. The nodes in a partition are not able to contact nodes participating in another isolated partition [34-35]. MANETs often experience the phenomenon of network partitioning [36-41]. The reasons behind it are high node mobility, restricted transmitting zone and the self-organized construction. In DHT-oriented routing mechanisms, mainly two critical challenges are faced due to the partitioning of networks in mobile ad hoc networks. These critical challenges are central reasons behind the degraded efficacy of the routing mechanisms based on DHT, one of which, is the inaccessibility of anchor nodes in the isolated and non-isolated topologies. Secondly, the depletion of logical identifier space is the consequence of network partitioning, and the lingering lookup delay associated with critical challenges.

A. Anchor Node Inaccessibility

In routing mechanisms dependent on DHT, the anchor node is responsible for stocking MD (mapping details) of another participating node over mobile ad hoc networks. Mapping details of the receiver participating node is indispensable for transmission between the sender and the receiver participating nodes. If the anchor node of the receiver participating node is unavailable in the connected topology, then MD of the receiver participating node is inaccessible. This phenomenon is the reason for the interruption of transmission among the sender and the receiver participating nodes in the logical topology. It infers that the accessibility of the receiver anchor node in the logical topology guarantees the persistent transmission between the sender and the receiver participating nodes.

Indeed, the partitioning of the network is responsible for the anchor node unavailability in the logical topology. Because of network partitioning of DHT-dependent logical topology into two or more independent networks, the sender and the receiver are members of one partition, but their respective anchor node lies in another isolated partition. In this scenario, the sender and the receiver participating nodes exist in similar partitions and are accessible to each other. Still, the sender and the receiver participating nodes are incapable of connecting. This phenomenon occurs because of the unreachability of mapping details stored at the receiver anchor node.

In Fig. 1 (b), a linked logical topology with a critical association n↔m is elaborated. This association between the participating nodes ‘n’ and ‘m’ is considered critical at a global level in the logical network over mobile ad hoc networks. The reason behind this consideration is that the participating nodes in the neighborhood of ‘n’ and ‘m’ are isolated. In a DHT dependent routing mechanism, every participating node is held responsible for stocking its MD (mapping details) at its anchor node for routing aims.

For example, a participating node ‘x’ stocks its mapping details (MD) at the anchor node ‘q.’ Now, if any other participating node, say the participating node ‘y’, wants to connect with the participating node ‘x’, then the sender participating node ‘y’ should first fetch the stocked mapping details from the anchor node ‘q’ of the participating node ‘x’. Afterwards, the participating node ‘y’ can initiate transmission with the receiver participating node ‘x’ in the logical topology.

In Fig. 2, the isolation of the critical association n↔m occurs in the logical topology over mobile ad hoc networks. Owing to the isolation of critical linkage in the logical topology, the partitioning of network topology takes place as presented in Fig. 2. After isolation of the network topology, the participating sender node 'y' and the receiver node 'x' remain in the identical partition. Although, the relative anchor node (i.e., node 'q') of the receiver node 'y' exists in another isolated partition in the logical network. In this scenario, the sender participating node 'y' is incapable of fetching the mapping details of the participating receiver node 'x' from the anchor node 'q'.

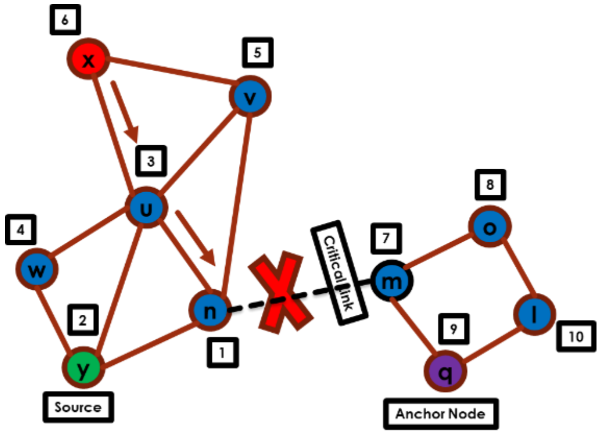


Fig. 2. Impossible retrieval of mapping details after network partitioning due to critical link failure.

Consequently, this phenomenon leads to the suspension of the interaction among the sender and the receiver participating nodes. Also, no participating node can fetch the mapping information of the receiver participating node 'x' in the absence of its anchor node in the logical environment. For smooth transmission, with other participating nodes in the logical topology, the receiver participating node 'x' should choose an updated anchor node and stock its mapping details. Afterward, the lookup queries targeting the participating node 'x' are efficiently rectified. However, the selection of another anchor node and stocking the mapping details on it becomes a reason for prolonged end-to-end delays and information depletion as well. Correspondingly, in case of failure or movement of anchor nodes to another partition, retrieval, or accessibility of stocked mapping details at that failed or moved anchor node should be assured to avoid the disruption of communication among the participating nodes in the logical network topology. It is considered as a critical issue in logical network topologies over mobile ad hoc networks that should be addressed efficiently in DHT-based routing schemes.

In the Fig. 3, the anchor node 'q' of the receiver participating node 'x' leaves the communication zone of another participating node 'm', and a new logical network identifier is allocated to it considering its neighborhood connectivity. Furthermore, the receiver participating node in this scenario chooses another anchor node 'o' and stocks its mapping details at the newly selected anchor node 'o' in the logical network topology. Simultaneously, this phenomenon becomes a reason for irretrievable enroute lookup requests by other participating nodes in the logical network topology. As a result, no transmission among the participating nodes is observed. In consequence, the DHT-based routing mechanism exhibits prolonged lookup delays and information depletion over mobile ad hoc networks.

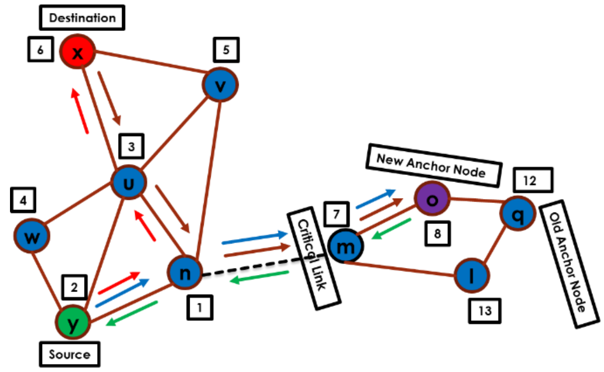


Fig. 3. New anchor node computation and stocking mapping details.

B. *Depleted Logical Identifier Space*

Another critical issue related to network partitioning that should be efficiently addressed is the depletion of logical identifier space. In a logical environment, the logical identifier space of an isolated partition can be reclaimed in another isolated partition. In consequence, the uniform division of the logical identifier space is achieved. Besides, isolated partitions can interact with each other due to the uniform division of logical identifier space. Therefore, retrieval of the logical identifier space is a well related critical challenge in DHT dependent routing schemes implemented over mobile ad hoc networks.

For this purpose, the pre-established network partitioning criterion performs an important responsibility for recognizing the occurrence of network partitioning in the logical identifier space over mobile ad hoc networks. There should be prompt, efficient pre-recognition of network partitioning until the authentic isolation of a logical network occurs in the logical environment. Pre-recognition is a necessary step towards effectively retrieving the logical identifier space in case of network partitioning activity in the logical environment over mobile ad hoc networks.

In a DHT-based routing mechanism, efficaciously recognition of network partitioning in a distributed manner is essentially required. The research community should rectify the identified challenge effectively to meet the requirements for the development of an efficacious DHT-based routing mechanism over mobile ad hoc networks. Moreover, in the scenario of network partitioning in MANETs, the prolonged lookup delays are observed. The prolonged lookup delay is a crucial associated issue that becomes worse when a critical challenge of network partitioning occurs over mobile ad hoc networks. This pertinent issue can be effectively resolved in a distributed way. For this purpose, the local neighborhood connectivity information of each participating node can be exploited. For the research community in this domain, resolving the said issue in a distributed fashion solicits strenuous exercise.

III. Solution Formulation

To rectify the issues related to network partitioning previously mentioned, a three-dimensional clustered distributed partition detection and replication routing mechanism referred to as 3DcPR is suggested. It exploits the local neighborhood connectivity information of the participating nodes for presenting the solution in a distributed fashion. The distributed resolution of the network partitioning-related challenges commensurate with the obligations of DHT dependent routing schemes in terms of scalability. In our mechanism for partition recognition, the following improvements have been explicitly suggested:

1) To offer the guarantee that the mapping details remain accessible in the disassociated partitions in the logical network. For this purpose, our mechanism dynamically replicates the mapping details in the logical network to handle the post-partitions replication challenges effectively.

2) To deal with the network partitioning, an effective mechanism is formulated to offer the recognition of network partitioning in a distributed fashion. This distributed partition recognition mechanism performs a decisive responsibility in identifying the network partitioning by considering several pre-established criteria. One of the criteria is the identification of the critical links among the participating nodes in the logical topology. Secondly, it focuses on offering an efficient strategy for the retrieval of the depleted logical identifier space due to partitioning of the network topology.

3) To encounter with the lingering lookup query delays, our mechanism provides the required efficacy in executing the replication management. Also, the influences of our replication management scheme considering the prolonged lookup delays are observed. It is found that lookup query delays are greatly minimized by exploiting our dynamic replication management strategy.

In 3DcPR, respective neighborhood connectivity information is exploited. 3DcPR exploits the neighborhood connectivity information up to two hops. It also utilizes the degree of the participating node for recognition of the critical links among the participating nodes in the logical environment. Furthermore, these parameters are considered for dynamic mapping details replication in the logical topology.

By doing so, 3DcPR guarantees the accessibility of mapping details in the isolated partitions after the occurrence of the network isolation phenomenon in the logical topology. As a result, the depleted information is significantly minimized. Also, our methodology is effectively coping with the partitioning of the network with remarkable reduction in the lingering delays of the lookup queries in the logical topology, achieved with no extra control overhead.

A. Recognition of Critical Linkage

In our methodology, HELLO messages among the logical cluster member nodes (LCMNs) are utilized for efficient recognition of network partitioning events in the logical environment over mobile ad hoc networks. In 3DcPR, every logical cluster member node reciprocates pre-established HELLO messages interval with each of its neighboring one-hop cluster members. In the HELLO message, information about the logical network identifier (LNI), logical space segment and a base network identifier of the participating cluster member is contained. Besides, the exchanged HELLO message consists of the one-hop neighborhood connectivity knowledge of the participating cluster member. It infers that each participating cluster member preserves the two-hop physical neighborhood connectivity knowledge in the logical topology for effective recognition of the network partitioning.

3DcPR recognizes a critical association among the two participating cluster members, say ‘n’ and ‘m.’ The association between the cluster members ‘n’ and ‘m’ is considered critical when one-hop neighborhood connectivity of cluster members ‘n’ and ‘m’ remains disconnected in case of failure or removal of the critical association between cluster members ‘n’ and ‘m.’ If a cluster member ‘n’ is one-hop critical of another cluster member ‘m,’ then all the neighborhood connectivity (one-hop) of the cluster member ‘n’ is not reachable from another cluster member ‘m,’ in case the cluster member ‘n’ is moved or failed. Due to this reason, the association among the cluster members ‘n’ and ‘m’ is considered critical. Besides, the association among the cluster members ‘n’ and ‘m’ is perceived as two hops critical in case the neighborhood connectivity (two-hops) of the participating cluster members ‘n’ and ‘m’ is not approachable in the absence of the critical association among the cluster members ‘n’ and ‘m.’

In 3DcPR, the state of the cluster members around the critical association is considered critical. Contrarily, the state of the cluster members, around the critical association, is perceived as non-critical. In 3DcPR, every cluster member informs all the neighbors (one-hop) about its state of being critical or not. For this purpose, each cluster member exploits HELLO messages. In the subsequent portions, the network partition recognition in a distributed manner along with a dynamic replication scheme is elaborated considering the clustering environment. Mostly, the gateways of the neighboring clusters serve as the critical cluster members around the critical association.

In 3DcPR, the k-hop neighborhood connectivity is considered for recognition of partition. Also, k-hop neighborhood connectivity information is considered for retrieval of a logical identifier structure. The k-hop neighborhood connectivity information is utilized for critical nodes recognition in the network. To attain the said objective, HELLO messages are occasionally exploited among adjoining cluster members to share neighborhood connectivity information (k-1 hop). In the HELLO messages, each cluster member shares neighborhood connectivity record (one-hop) with neighboring cluster members considering ‘k’ that equals 2. Moreover, the base network identifier, logical network identifier, and logical space segments are exchanged in the periodic HELLO messages. Hence, every cluster member keeps neighborhood connectivity information up to two-hops in the network.

The imperative step towards successful and efficient recognition of network partitioning is the timely detection of critical association among critical cluster members. For example, consider two participating critical cluster members ‘n’ and ‘m’ around the critical association n↔m. The occurrence of network partitioning phenomenon is provoked by the 3DcPR in a distributed fashion. This partition detection strategy considers precautionary actions involving the adjustment of a logical identifier structure. Besides, a specific duration of time is set. This set timer is termed as partition timer. Network partitioning happens if a critical cluster member ‘n’ around the critical association n↔m does not receive the HELLO messages from another participating cluster member ‘m’ after the pre-established HELLO break. In our mechanism for partition recognition, the pre-established partition timer is three times the HELLO break.

In the same way, the other participating cluster member recognizes the partitioning of the network. If partitioning of networks happens, then the cluster members around the critical association are responsible for retrieval of the misplaced logical identifier structure. For this purpose, the cluster members utilize the misplaced logical identifier structure in the separated independent partitions.

Mostly, the exploited logical identifier construction plays a vital role in the retrieval process of the logical identifier structure. The LIS recovery mechanism depends on the logical structure used. Every participating cluster member around the critical association retrieves the logical identifier structure in the three-dimensional space. For this purpose, every cluster member around the critical association retrieves it by just altering the value of the dimension. Correspondingly, the retrieval process in the chord construction is somewhat different. In the chord construction, logical network identifiers of the participating nodes around the critical association are altered for retrieval of a misplaced logical identifier structure. They modify their logical network identifiers considering the linkage (successor or predecessor) among the participating nodes around the critical association.

In the chord construction, the participating node (successor) retrieves the logical identifier structure by altering the logical network identifier to S. Also, the participating node (predecessor) in the chord construction modifies the logical network identifier to E for the successful retrieval of the misplaced logical identifier structure. The precedent participating node concerning the logical chord formation revives the logical identifier space by altering its logical network identifier to E, and also the descendent participating node in the chord formation recuperates the logical identifier space by modifying its logical network identifier to S. The exploitation of the misplaced logical identifier structure in the separated independent partitions has great benefits. One of the benefits is the uniform distribution of logical identifier structure in the separated independent partitions.

Our strategy suggests an efficient distributed methodology for recognition of partition. In it, the recognition is entirely distributed in nature. It exploits the local neighborhood connectivity knowledge of the participating cluster members for partition recognition in a distributed manner. It does not consider the dissipation of control knowledge at the global level.

B. *Partition Recognition and Replication Strategy*

To test 3DcPR, let us consider a 3DcRP [27] example as depicted in the following scenarios, for explaining the feasibility of our methodology for partition recognition and replication.

Initially, 3DcPR recognizes the critical association and corresponding critical participating cluster members. For this purpose, HELLO messages are exploited by our partition recognition and dynamic replication methodology, i.e., 3DcPR. Every cluster member occasionally exchanges local neighborhood connectivity knowledge (one-hop) with the neighboring cluster members by exploiting the HELLO messages. By doing this, every cluster member in the network contains the neighborhood connectivity knowledge (two-hops). In the HELLO messages, a logical network identifier, base network identifier, and logical space segment are exchanged. Maintaining the neighborhood connectivity knowledge (two-hops) facilitates in recognition of critical association and corresponding critical cluster members in the logical network.

To understand this, consider the example scenario depicted in Fig. 4. In this scenario, one-hop neighboring cluster members of ‘w’, ‘x’ and ‘z’ are {‘u’, ‘y’, ‘x’}, {‘v’, ‘u’, ‘w’, ‘x’, ‘z’}, and {‘x’, ‘y’, ‘v’}, respectively. When the participating cluster members, ‘w’, ‘x’ and ‘z,’ exchange the local neighborhood connectivity knowledge (one-hop), then another participating cluster member ‘v’ in cluster 1 with LNI 1 contains the local neighborhood knowledge (two-hops). The participating cluster member ‘v’ reviews the neighborhood connectivity knowledge (one-hop lists) of all its adjoining cluster members (cluster members ‘x’ and ‘z’) for searching the nexus cluster member among them. The participating cluster member ‘v’ does this exercise for broadcasting its state (either critical or not critical). In this exercise, the participating cluster member ‘v’ does not include itself. After reviewing the neighborhood connectivity knowledge (one-hop lists) of all its adjoining cluster members, the participating cluster member ‘v’ finds that a cluster member (also the gateway cluster member), say ‘y’, is the nexus cluster member among the neighborhood member ‘v’ failure does not have an impact on the connectivity. This connectivity {‘x’, ‘u’, ‘w’, ‘y,’ ‘z’} exists despite its (‘v’) failure or movement. Therefore, the participating cluster member ‘v’ announces its state as non-critical. Likewise, the participating cluster member 'y' hears the local neighborhood connectivity knowledge (one-hop) from each of its adjoining cluster members ‘’w’, ‘x’, ‘z’, and ‘m.’ This one-hop neighborhood connectivity lists are {‘u’, ‘x’}, {‘v’, ‘u’, ‘w’, ‘y’, ‘z’}, {‘v’, ‘x’, ‘y’}, {‘r’, ‘p’, ‘q’, ‘y’} from ‘w’, ‘x’, ‘z’, and ‘m’, respectively.

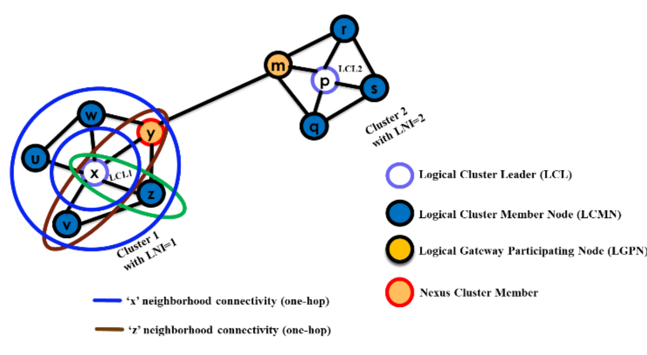


Fig. 4. Nexus cluster member identification procedure.

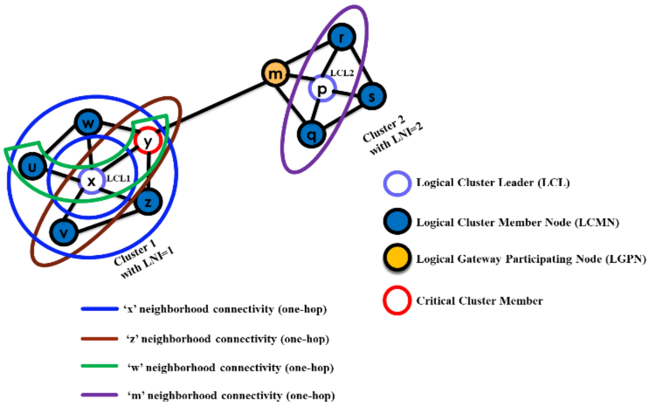


Fig. 5. Critical cluster member identification.

It is depicted in Fig. 5 that the nexus cluster members among the adjacent cluster members ('w,' 'x,' 'z') of 'y' exists. It constitutes a linked network without the cluster member 'y.' Although, the one-hop neighborhood connectivity of the participating cluster member 'p' of cluster 2 with LNI 2 (also the gateway cluster member) does not become a part of the linked network of cluster members 'w', 'x', and 'z'.

It infers that the state of the two participating cluster members 'y' and 'm' is set as critical. They both also act as the gateway cluster members in clusters 1 and 2, respectively. In consequence, the association among the critical cluster members 'y' and 'm' is considered as critical.

For the example scenario as depicted in Fig. 6, the critical association is y ↔ m. Correspondingly, every participating cluster member refreshes its state of being critical or not in the network periodically. When a newly joined cluster member, say 'w,' in cluster 1 calculates its logical network identifier and it stocks its mapping details at its anchor cluster member, say 'q,' afterward. For this purpose, the newly joined cluster member 'w' sends cluster member 'y' stocks the mapping details of the newly joined cluster member 'w' if that mapping details are not sent by the other critical cluster member in the network.

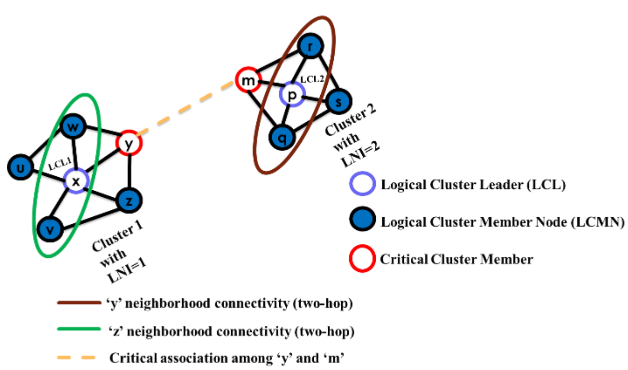


Fig. 6. Critical association identification.

The critical cluster members 'y' and 'm' stock the mapping details for forwarding it further. Therefore, the critical cluster members 'y' and 'm' around the critical association y↔m, and logical cluster leaders (LCL1 and LCL2) maintain a copy of the mapping details included in the MPTA message. The phenomenon of replicating and retrieving mapping details before the occurrence of network partitioning is depicted in the Fig. 7. This dynamic replication strategy facilitates avoiding communication disruption in the separated partitions after the occurrence of network partitioning. The cluster members in two partitioned networks can acquire the mapping details from the critical cluster members 'y' and 'm' across the critical association and the logical cluster leaders (LCL1 & LCL2) as well.

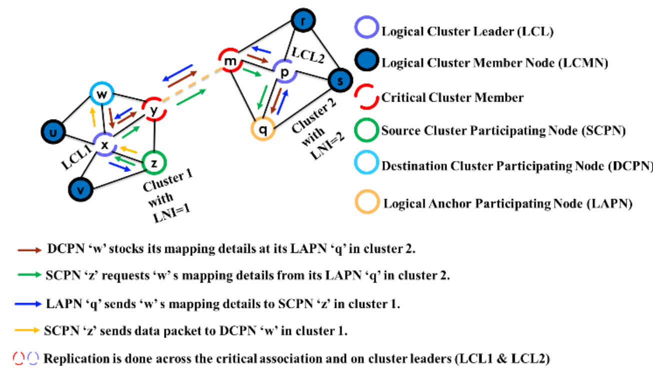


Fig. 7. Replication around the critical association and on cluster leaders.

By doing so, the participating cluster members can communicate in a partition after the failure or removal of the critical association in the network. In the Fig. 8, an example scenario is depicted to elaborate the phenomenon after the occurrence of network partitioning. In this example scenario, a sender logical cluster member node 'z' in cluster 1 having cluster leader 'x' wants to contact another receiver logical cluster member node 'w.' For this purpose, the sender cluster member 'w' first finds the anchor cluster member for the receiver cluster member 'w.' After finding the anchor cluster member, i.e., 'q' of the receiver cluster member 'w,' the sender cluster member 'z' acquires the stocked mapping details from the anchor cluster member 'q' of 'w.' The stocked mapping details is not accessible for the sender cluster member 'z' if the critical association among the critical cluster members 'y' and 'm' fails or removes.

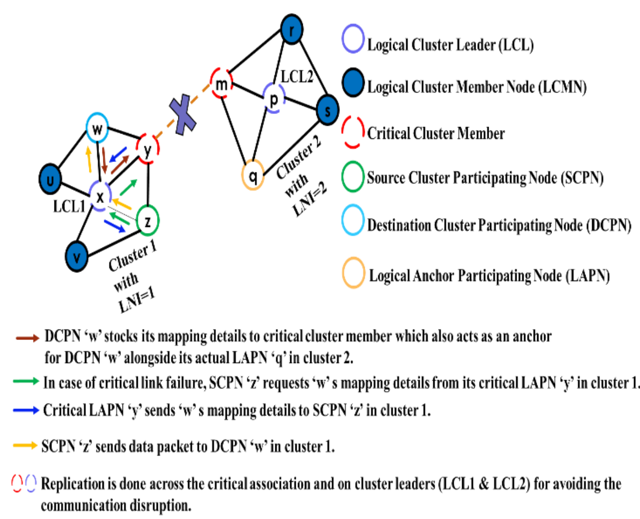


Fig. 8. Avoiding communication disruption after network partitioning.

Our methodology provides an effective solution to this unavailability of mapping details in case of critical association failure. It gives assurance to provide accessibility of mapping details after the failure of critical association (occurrence of network partitioning). In our methodology, pre-partitioning precautions like recognition of the critical association/critical cluster members and dynamic replication assist in avoiding the unavailability of the mapping details. In the above example scenario, the pre-partitioning criterion (replicas placement) assists the sender cluster member 'z' to retrieve the mapping details of the receiver cluster member 'w' from the critical cluster member 'y' although the network partitioning occurred due to the failure or removal of critical association among critical cluster members as depicted in Fig. 8. Even if the critical cluster member 'y' fails or moves to another location, the sender cluster member 'z' can obtain the replicated mapping details of the receiver cluster member 'w' from the cluster leader 'x.' Therefore, our methodology effectively addresses the identified issue by replicating the mapping details on both the critical cluster members around the critical association and cluster leaders.

Furthermore, 3DcPR activates the occurrence of network partitioning in case the critical cluster members around the critical association are not able to receive HELLO messages from each other for a specific pre-established time duration (partition-timer). Although, it is a must for the critical cluster members to be both one-hop and two-hops critical. However, the exception is for the critical cluster member that is two-hops critical but has a state of one-hop non-critical as well. In the Fig. 9, it is depicted that critical cluster members 'y' and 'm' around the critical association y↔m are not able to receive the HELLO messages from each other, then this phenomenon provokes the network partition after the expiry of the pre-established partition timer.

In this scenario, the respective critical cluster members retrieve or reiterate the depleted logical identifier space. If the anchor cluster member is considered as the critical cluster member, then it mirrors its MD (mapping details) around the critical association in the network. To avoid the communication disruption after the network partition, the mirroring deployment and retrieval of logical identifier space is an important step. This situation may give rise to uniform and distributed separated partitions though there exists network partitioning. The retrieval process of logical identifier space is different for every logical construction. Because this retrieval process is dependent on the construction of logical identifier space, the exploited logical construction may include a ring, a cord, a tree, or a 3D.

In the case of a high mobility environment, DHT-oriented routing methodologies, over mobile ad hoc networks, face prolonged lookup delays and decreased overall performance. Our methodology utilizes the dynamicity of the mobile ad hoc networks. It means the relative connectivity, i.e., two-hop topological knowledge. Moreover, our methodology utilizes the local network variation (one-hop connectivity knowledge). For relative connectivity and local network variation, periodically sent HELLO messages are utilized by the 3DcPR. By doing so, it offers assured reachability/availability of the network. Besides, it is done with no additional control overhead. As a result, end-to-end delays are effectively minimized for lookup queries in the network.

IV. Results and Discussion

To assess the effectiveness of the proposed mechanism, the network simulator version 2.35 is exploited for creating and running every simulation. NS-2.35 is an open-source event network simulated adopted by the research community. The propagation model utilized by the proposed mechanism is Two Ray Ground. This propagation model is exploited to simulate IEEE 802.11 concerning the standard values for physical and link layers. In Table III, the simulation parameters are demonstrated. The effectiveness of the proposed mechanism i.e., 3DcPR is evaluated with the existing logical networks over MANETs strategies like 3DDR [23] and 3DRP [24]. These previous strategies exploit the three-dimensional shape to efficiently cope with the mismatch issue among the logical and physical network topologies. Besides, the existing strategy i.e., 3DDR provides notable resiliency against participating node movement or failure situations. The participating node calculates its logical network identifier considering the LNIs of each neighboring participating nodes within a network. Consequently, a significant escalation concerning control, computation and routing traffic overheads is observed. Conversely, a logical cluster leader (LCL) is devoted for distributing the logical network identifiers among its logical cluster member nodes residing within its logical cluster concerning the proposed mechanism i.e., 3DcPR. This phenomenon remarkably minimizes the control, computational, and routing traffic overheads within the network.

The playground area size is considered as 1000m * 1000m as per the proposed methodology for efficiently conducting the simulations in NS 2.35. The utmost broadcasting span is set as 50 m. Remember, the broadcasting span is adopted in a manner that passes over each participating nodes a specific distance i.e., two hop. In 3DcPR, HELLO notifications are regularly interchanged and utilized for effectively preserving the neighborhood connectivity among the adjacent participating nodes in the network. The uniform distribution is implemented when establishing a tangible network simulation environment. In addition, as demonstrated in Table III, the network simulations are employed concerning motion patterns by exploiting the high mobility of the participating nodes i.e., 7 m/s to 25m/s. The exact cause of constricting the speed of the participating nodes from 7m/s to 25m/s is the unsustainability of MANETs considering considerably high or low mobility situations. Moreover, a consistent selection of the participating nodes' speed is adopted as 7m/s to 25m/s. For maintaining the connection in the physical network, BonnmotionV2 is exploited in the current scheme for generating the mobility cases in accordance with RWP (random way point) network model. RWP is the first choice of renowned researchers of the wireless domain for perfectly assessing the effectiveness of the ad hoc networks alongside its other prominent benefits like ease and quick functionality. Remember, OLSR is being exploited by the proposed scheme as an underlying strategy. Moreover, 10 unique files are commissioned by every participating node as per the proposed strategy. Also, for modelling routing traffic, the random traffic pattern is employed by 3DcPR. For establishing the data traffic, the CBR (constant-bit-rate) flows are utilized over the UDP protocol. In addition, it is supposed to be the connectivity of network formation for both 3DcPR and 3DDR. In our experiments, ten executions per case are done. The aggregate results are depicted by utilizing graphs. Lastly, the simulation duration is established as 500 seconds for performing different scenarios for accurately evaluating the performance of the proposed and existing mechanisms.

TABLE III. SIMULATION PARAMETERS

Parameter	Value
Playground Size	[1000 m × 1000 m]
Number of Nodes	[25-400]
Transmission Range	50 m
Simulation Time	500 s
Data Rate	[1- 500pps]
Start of Data Transmission	[70, 300]
End of Data Transmission	[250, 499]
Node Speed	[7 m/s – 25 m/s]
Traffic Model	Random Traffic Pattern
Mobility Model	Random Way Point
Radio Propagation Model	Two Ray Ground

In this research article, three performance parameters are considered for efficiently assessing the performance of the suggested mechanism. These performance parameters are evaluated against the high mobility of the participating nodes and rising network size.

1) Routing Traffic Overhead (RTO): It is the entire control overhead packets as utilized by the routing protocol in the mobile ad hoc network.

2) Packet Delivery Ratio (PDR): The ratio between the total mapping request packet (MREQ) initiated and the total MREQ entertained successfully by receiving the mapping reply packets (MREP).

3) Average End-To-End Delay: The average time elapsed between when the source node initiates MREQ and the source node gets MRPY.

A. Average End-To-End Delay

To evaluate the performance of a DHT-based routing mechanism, the average end-to-end delay is considered as an important criterion. Through this criterion, the entire network performance can be assessed as well. It is required to perform a detailed investigation concerning the effect of rising network size alongside the speed of the participating node over aggregated end-to-end delay. The detailed impact analysis of increasing network size and node moving speed over average end-to-end delay is carried out and demonstrated in the following Fig. 9.

In the Fig. 9, the average end-to-end delay of 3DcPR, 3DDR [23], and 3DRP [24] is computed against the changing speed participating nodes ranging from 7m/s to 25m/s considering the increasing network size It is demonstrated in Fig. 9 that the average end-to-end delay of the proposed mechanism i.e., 3DcPR is notably decreased in contrast to the existing schemes 3DDR, and 3DRP. The central reason behind this significant reduction in average end-to-end delay is novel partition discovery and effective replication strategy in a distributed way which discovers the censorious participating nodes first and clones the mapping details for facilitating the uninterrupted connection. The average end-to-end delay is considerably minimized as the extra clones are deployed in the network to avoid transmitting the message request to the actual anchor participating node rather than a nearby participating node carrying the mapping details acting as a clone. As a result, the traffic overhead is significantly decreased considering the proposed mechanism i.e., 3DcPR in comparison to the existing schemes 3DDR, and 3DRP.

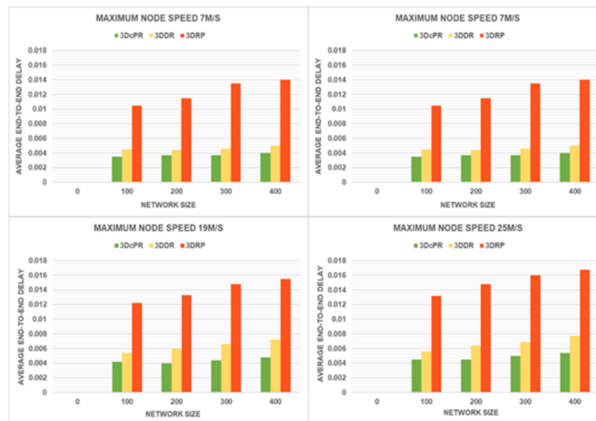


Fig. 9. Average end-to-end delay vs. network size.

Moreover, the notable reduction in routing traffic overhead minimizes the contention to establish the connection with the medium at media access layer considering IEEE 802.11. Furthermore, this phenomenon assists in remarkably decreasing the average end-to-end delay concerning the suggested mechanism.

B. Routing Traffic Overhead

One of the critical parameters to evaluate the performance of the proposed mechanism considering the increasing network size alongside the fluctuating participating node speed is the routing traffic overhead. Specifically, the routing traffic overhead gains immense value when it is computed for each lookup query in the network. As demonstrated in Fig. 10, the routing traffic overhead is computed for the proposed mechanism i.e., 3DcPR in comparison to the existing strategies 3DDR, and 3DRP considering the fluctuating participating node speeds i.e., 7m.s to 25m/s and changing network size. A remarkable decrease in the routing traffic overhead is observed as depicted in Fig. 10 for the proposed mechanism considering the varying network size and fluctuating participating node speeds in comparison to the existing schemes. The reason behind this significant decrease in the routing traffic overhead is the novel partition discovery mechanism alongside the effective replication scheme. This proposed strategy discovers the critical participating nodes in the network and replicates the mapping details which results in minimized lookup request overhead in the network. Remember, as the participating nodes over MANETs have fluctuating speeds which results in frequent network construction changes. Consequently, this phenomenon increases the routing traffic and lookup requests overhead over MANETs.

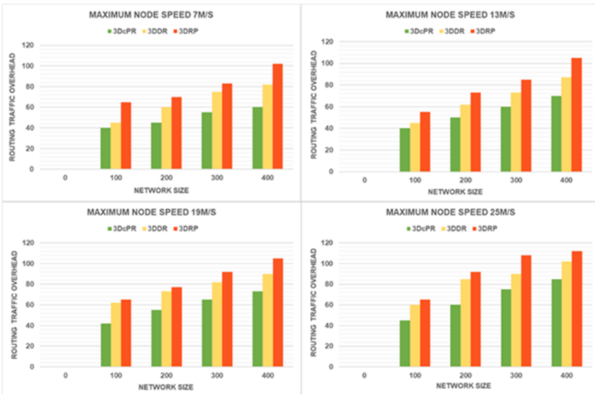


Fig. 10. Routing traffic overhead vs. network size.

The primary reasons behind this rise in the routing traffic overhead are the relocation the anchor participating nodes, stocking the mapping details at newly relocated anchor participating nodes, the retrieval of the logical identifier construction, and re-computation of logical network identifiers happen due to the network partitioning. As demonstrated in Fig. 10, the calculated routing traffic overhead for the proposed scheme i.e., 3DcPR is much lesser than the existing strategies due to the discovery of critical participating nodes and corresponding critical association between them in the network and the novel replica management strategy. Besides, the proposed scheme i.e., 3DcPR utilizes the clustering environment and three-dimensional network construction for arranging the participating nodes in logical network over MANETs.

C. Packet Delivery Ratio (PDR)

As discussed earlier, the potential of a routing mechanism is the effective delivery of data packets towards the destination participating node in the network which is termed as the packet delivery ratio. Remember, the increasing number of participating nodes minimizes the packet delivery ratio concerning the routing mechanism. As known, with the increase in number of participating nodes raises the collision of packets at media access control layer concerning IEEE 802.11. It infers that the reduction in successful message request and message reply alarms happens in the network because of escalating collision of packets in the network. Additionally, the number of hops among the source and destination participating nodes rises in the network. Consequently, this phenomenon amplifies the total amount of transmission in the network. Hence, packet delivery delays are observed in the network and there are more chances of collision of packets concerning media access layer. As a result, the effective transmitting of message request and message reply alarms is badly affected in the network.

In Fig. 11, the packet delivery ratio for the proposed mechanism i.e., 3DcPR and the existing schemes is computed. As demonstrated in Fig. 11, the effect of increasing number of the participating nodes alongside the fluctuating speeds is observed lower for the proposed mechanism i.e., 3DcPR in contrast to the existing strategies 3DDR, and 3DRP. Hence, the proposed mechanism 3DcPR achieves better results concerning packet delivery ratio in comparison to the existing schemes which proves the efficaciousness of the proposed methodology. Besides, this particular potential of the proposed mechanism makes it a strong candidate for its execution and efficient transmitting of packets in a large-scale mobile ad hoc networks.

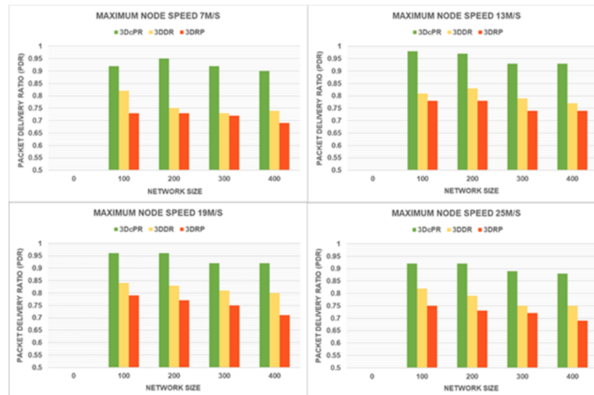


Fig. 11. Packet delivery ratio vs. network size.

In addition, the packet delivery ratio concerning 3DcPR is preserved and enhanced by utilizing the proposed partition discovery and replica management strategy. The proposed methodology clones the mapping details on each censorious connectivity down the route towards the logical anchor participant. This phenomenon is the reason behind the enhanced packet delivery ration for the proposed methodology as the mapping details are accessible even in the split partitions considering the occurrence of network partitioning. Besides, the high mobility of the participating node and fluctuating network size provoke the partitioning of the network over MANETs. So, in case of network partitioning, it is almost impossible to fetch the mapping details considering the existing methodologies like 3DRP, and 3DDR. The reason behind this inaccessibility to mapping details is the existence of logical anchor participant in the split partition. Additionally, in the proposed approach, the replica preservation around the critical connectivity down the path towards logical anchor participant enhances the reliability of 3DcPR. The other reason behind this reliability enhancement of 3DcPR is significant decrease in routing traffic overhead. Consequently, at the media access layer, the collision of packets is notably minimized. The proposed methodology i.e., 3DcPR preserves this scenario for long which results in significant improvement in delivering the packets towards the destination. Moreover, the existing schemes exhibits the mismatch issue among the physical and logical network topologies. Consequently, the existing methodologies suffer from lengthy paths towards destination and unnecessary routing traffic in the network. On the other hand, the proposed methodology i.e., 3DcPR considers three-dimensional construction in a clustering environment to perfectly map the physical linkage in the logical network and avoiding the mismatch issue.

V. Conclusion and Future Directions

One of the critical problems concerning the DHT-oriented routing over mobile ad hoc networks is the partitioning of networks. Specifically, network partitioning phenomenon becomes worsen in case of high mobility and with the rising number of the participating nodes in the network. Consequently, the mapping details are inaccessible, the logical identifier construction is dissolved, and lengthy lookup delays are observed considering the occurrence of network partitioning. As a result, no communication within the mobile ad hoc network. So, the prompt discovery of network partitioning over MANETs is a demanding task considering the high mobility and increasing network size of the participating nodes in the network. In this research article, the issue of network partitioning over MANETs is tackled by developing a novel mechanism in a distributed fashion. A novel partition discovery mechanism alongside the effective clone management strategy is recommended to successfully deal with the partitioning of network over MANETs. Also, a distinct and effective replication mechanism is proposed which results in minimized lookup and routing delays considering the DHT-oriented mobile ad hoc networks. The prompt preventive actions e.g., clone management and neighbourhood connectivity knowledge of the participating nodes are considered for discovering the network partitioning in time and effectively handling the issues after network partitioning. As a future work, the implementing of the proposed methodology for secure data dissemination in mobile ad hoc networks is under consideration.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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