A Three-dimensional Clustered Peer-to-Peer Overlay Protocol for Mobile Ad Hoc Networks

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Abstract

Peer-to-peer (P2P) computing involves exchanging resources and files by computers connected through a network rather than a central server. In P2P, over mobile ad hoc networks (MANETs), the fundamental necessity is the linkage of the overlay participating peers (OPPs) for the efficient operation of the DHT-based P2P overlay protocol over MANETs. This necessity becomes more critical in a high mobility environment. Due to the high mobility of OPPs, the topology of the P2P overlay is altered continuously. Consequently, the efficiency of DHT-based P2P overlay protocol over MANETs greatly decreases due to the increased lookup latency, maintenance, computational, and control overheads. In the current research, a novel three-dimensional clustered overlay P2P protocol, i.e., 3DCOP, is suggested to cope with the identified issues. Simulation results depict that 3DCOP performs better in routing overhead, false-negative ratio, path-stretch ratio, and file discovery delay in the high mobility environment over MANETs.

Keywords: Overlay participating peer; Overlay network label; Distributed systems; Self organizing networks.

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1. Introduction

In peer-to-peer networking, the workload is divided among the overlay participating peers. P2P networking framework offers fault tolerance, robustness, and allocation of resources in a distributed fashion. Each participating peer, in the P2P overlay impulsively creates a linkage with other overlay participating peers. It is essential to mention that no critical centralized collaboration is required in P2P networking [1–4]. Different resources (files, memory, and CPU) are efficiently distributed in the peer-to-peer overlay networking. In the previous decade, an exceptional, consistent development has been observed in wireless and mobile communication - the processing power and memory of the recent wireless and mobile devices are improving daily. Therefore, different types of content like audio, video, pictures in various formats, and textual information can be retained for future use by exploiting these devices' efficacy, which operates in a restricted transmission zone.

Consequently, they do not require a proper centralized network framework for contacting each other. Wireless and mobile devices utilize wireless fidelity (WI-FI) or Bluetooth for communication purposes, enabling these devices to construct a self-sustain network termed as a mobile ad hoc network. Through a MANET, wireless and mobile devices can contact each other and efficiently perform resource allocation functionalities without a centralized infrastructure.

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To share the content (audio, video, images, and textual information), OPPs become a part of the overlay topology (joining procedure), or they leave it for the said purpose. P2P can serve as the best suitable paragon for the self-sustaining mobile ad hoc networks. The reason behind it is that a MANET does not exhibit a centralized communication framework. In this way, a P2P overlay over a MANET offers enormous benefits to its participants ranging from stocking the resources and retrieving them in an efficacious manner. P2P overlay network accommodates two types of nodes, i.e., an overlay participating peer and a non-overlay participating peer (N-OPP). An OPP can share the content (audio, video, images, and textual information) with all the other OPPs in the P2P overlay over a MANET and precisely performs the content retrieval operation. Conversely, the N-OPP does not share or retrieve the content and does not participate in the overlay network. The P2P overlay is built at the application layer and relies on an underlying routing protocol at the network layer for forwarding purposes.

Currently, various cluster-based structured P2P overlay approaches [5–8] have been proposed by the prominent researchers over ad hoc networks. The P2P overlay scheme over a MANET should incorporate scalability and robustness in avoiding the arising issues, i.e., the mismatch problem, the increased traffic, computational, maintenance, and control overheads. The inflexibility of the overlay construction badly affects the efficacy of the P2P overlay protocol over mobile ad hoc networks. Consequently, longer end-to-end delays, increased path-stretch ratio, and higher file retrieval delays are observed. Thus, an effective clustered P2P overlay protocol over MANETs in the high mobility environment is substantially required to avoid all the identified issues.

Table 1: Acronyms & Abbreviations .

PNT	Physical Network Topology
ONT	Overlay Network Topology
PNL	Physical Network Label
ONL	Overlay Network Label
OLZ	Overlay Labelling Zone
OLZS	Overlay Labelling Zone Segment
OPP	Overlay Participating Peer
N-OPP	Non-Overlay Participating Peer
OPC	Overlay P2P Cluster
OCL	Overlay Cluster Leader
OCM	Overlay Cluster Member
OGPP	Overlay Gateway Participating Peer
SMK	Stocked Mapping Knowledge
OAPP	Overlay Anchor Participating Peer
MPTN	Mapping Petition Notification
MRN	Mapping Reply Notification
SOPP	Source Overlay Participating Peer
DOPP	Destination Overlay Participating Peer
RTO	Routing Traffic Head
FNR	False-Negative Ratio
PSR	Path-Stretch Ratio

In this paper, a novel 3D clustered P2P overlay protocol over the mobile ad hoc networks is suggested, named 3DCOP, in the high mobility environment. It utilizes the 3D clustered overlay construction over MANETs that effectively preserves the physical neighborhood connectivity information of the OPPs in the high mobility environment. The proposed protocol significantly assists in avoiding the mismatch problem among the physical and overlay network topologies. Furthermore, the proposed 3D clustered overlay efficiently addresses the issues of increased traffic, computational, maintenance, and control overheads in case of OPP's join and leave operations. Although the logical clusters are introduced in our previous work [9], yet it is utilized only for routing purposes at the networking layer level. To the best of our knowledge, the proposed methodology is the premier endeavor for exploiting the 3D clustered overlay construction for organizing the OPPs at the overlay on top of MANETs in the high mobility environment. Additionally, it convincingly considers physical neighborhood connectivity information of OPPS at the application layer level. The overlay network labels (ONLs) are allocated to the OPPs in the 3D clustered P2P overlay over MANETs. The prevailing P2P overlay protocols on top of ad hoc networks do not consider the exploitation of 3D construction in conjunction with overlay clusters at the P2P overlay in a high mobility environment to preserve the physical neighborhood connectivity of the OPPs. The clustered P2P overlay protocol over MANETs, i.e., 3DCOP, works at the application layer to efficiently share and retrieve the content (audio, video, images, and textual information). For routing the packets from source to destination, the proposed scheme considers the routing operation performed by an underlying routing protocol (OLSR in this case). In 3DcRP [9], a DHT-based routing protocol is proposed to implement routing operations at the network layer. In [9], the sharing and retrieval of the content (audio, video, images, and textual information) is not done at the application layer level. The Table 1 and Table 2 provide the abbreviation and definitions of important terminologies used in this paper. The significant novel research contributions of our research work are as follows:

- We have developed an effective DHT-based P2P overlay mechanism to work at the application layer over MANETs efficaciously.
- We have designed and developed a novel 3-dimensional DHT-based clustering P2P overlay protocol, i.e., 3DCOP for mobile ad hoc networks that introduces a novel concept of P2P overlay clustering at the application layer for efficiently dealing with the high mobility of overlay participating peers over MANETs.
- We have introduced an effective novel replica management strategy that replicates the mapping information at the overlay cluster leaders and various OPPs to minimize lookup latency and lookup traffic greatly.
- We have proposed an efficacious technique that decreases the routing traffic overhead, control, and computational overheads by limiting the communication only within the overlay cluster leaders (OCLs) for large-scale MANETs with high node mobility. Involving only OCLs for communication would greatly help reduce the bandwidth utilization that results in increasing the overall throughput of the network.
- We have curtailed the path-stretch-penalty that avoids indispensable prolonged paths among OCLs. These lengthy paths occur because of the mismatch problem. The mismatch problem happens when neighbors of a node in the physical network are not the same in the P2P overlay network.
- We have suggested an efficient technique that offered greater flexibility in choosing a path from source to destination by the efficient use of overlay cluster leaders and gateway OPPs in the network. This phenomenon would help boost the overall network performance against the failure of an OPP or its dynamic mobility. As a result, the end-to-end delay is reduced, and the total throughput of the network increases. Furthermore, it would also help avoid the partitioning of the network.

Table 2: Definitions of Important Terminologies

Overlay Network	It is the connectivity of OPPs considering their ONLs.
Physical Network	The underlying network that provides physical connectivity.
Overlay Participating Peer	The node participating in the overlay network topology.
Non-Overlay Participating Peer	The node which is not participating in the overlay network topology.
Physical Network Label	The unique MAC address of the OPP in the physical network.
Overlay Network Label	The network label of OPP in the ONT.
Overlay Cluster Leader	The leader of the overlay P2P cluster by utilizing the highest node degree.
Overlay Cluster Member	The member of the overlay P2P cluster attached to the overlay cluster leader.
Overlay Anchor PP	OAPP stores the mapping knowledge of other nodes in the network.
Overlay Gateway PP	OGPP is the node that exists in the communication zones of more than one OCLs.
Overlay Labelling Zone	OLZ is an addressing zone from where each OPP acquires its ONL.

The rest of this paper is organized as follows: Section 2 highlights the existing related research work issues. In Section 3, the problem statement is elaborated. In Section 4, the proposed novel P2P overlay protocol, i.e., 3DCOP for MANETs, is presented in detail. The performance analysis of the proposed scheme is demonstrated in Section 5. Finally, Section 6 concludes the paper along with future directions.

2. LITERATURE REVIEW

E. Jakab et al. [10] suggests an efficient, scalable DHT-based routing protocol termed dynamic addressing routing (DART) for ad hoc networks. In DART, routing information is managed proactively. Every node acquires its logical identifier considering its neighboring physical nodes. The DART does deal with high mobility scenarios. Mainly, it addresses the scalability in ad hoc networks but for low mobility scenarios. In the case of high mobility scenarios, DART exhibits significant traffic overhead.

C. Marcello et al. [11] presents a DHT-based routing mechanism termed as multipath routing protocol (MDART) for offering scalability in ad hoc networks. It is a hierarchical DHT-based multipath routing scheme. To gain access to the destination node efficiently, MDART proactively manages every possible path through the subsequent nodes in the tree logical network. The mismatch issue is not eliminated ideally by exploiting the tree formation in the MDART. The MDART routing scheme does not address the network partitioning and merging scenarios.

C. Matthew et al. [12] suggests a routing mechanism termed as virtual ring routing (VRR). The VRR is a routing approach based on the logical network built by a DHT structure. In the VRR, the participating nodes are arranged in the form of a virtual ring by maintaining logical identifiers' increasing order. Besides maintaining the list of virtually closest participating neighbors, a list of neighbors in the physical network is also considered by every participating node to contact each other immediately. Then, it sends the message towards the destination node. One of the issues with VRR is that the adjacent nodes in the virtual ring topology may be distant in the physical topology. As a consequence, a message forwarding process may span longer than usual. Another critical issue is scalability in the VRR.

A. Abdalkarim et al. [13] suggests a routing mechanism termed as a virtual chord protocol (VCP). In it, a logical topology is created over the existing physical topology. The VCP utilizes a chord formation having logical identifier space stretches between 0 to 1. A new node's logical identifier is allocated following the logical identifiers of all its one-hop physical neighbors. The predecessor and successor in a participating node's physical topology are retained in the logical topology as neighbors by every node. The greedy forwarding strategy is exploited by the VCP, which utilizes both the physical and logical neighborhood knowledge to forward the message to the destination node successfully. The mismatch issue arises in a bid to preserve both the physical and logical neighborhood connectivity. As a consequence, longer end-to-end delays and increased traffic overhead are observed.

A. Shahbaz et al. [14] utilizes a 3D structure for scalable routing in MANETs. In this scheme, every node mirrors the physical neighbors in the 3D coordinate system. In the logical identifier space, nodes' physical neighborhood connectivity (Intra/inter neighborhood links) is maintained. This scheme efficiently evades the mismatch problem between the physical and logical topologies in a DHT-based environment on top of MANETs. However, it is not considered a practical methodology for high mobility environments in avoiding the mismatching issue. In this scheme, every node must compute the LID again when it changes its location, increasing the computational overhead by raising the number of nodes in the network. This phenomenon becomes worse in the case of a high mobility environment.

J. Sourabh et al. [15] suggests a scalable DHT-based unicast routing mechanism termed as virtual identifier routing, i.e., VIRO. In the VIRO, a topology-aware virtual id space is created. The logical identifier of a node is calculated based on its distance from the network's root node. The allocation of logical identifiers is carried out based on two standards. One of the set criteria is that the logical neighborhood connectivity should be preserved in the physical topology. The other set standard in VIRO is that one node in a sub-tree should connect to another sub-tree. The VIRO routing protocol is suggested for the low mobility scenarios.

G. Jose Joaquin et al. [16] suggests a DHT-based routing mechanism termed as automatic incremental routing, i.e., AIR. The AIR addresses the two crucial routing challenges, scalability and flooding. In the AIR, every node consists of a universal identifier and acquires its logical identifier in the logical network creating a labeled directed acyclic graph LDAG. The formation of the LDAG in the logical network is created considering a delegated node termed as a root node. The participating nodes interchange hello messages periodically to create an LDAG. The AIR routing mechanism is dependent on a tree structure in the logical identifier space. As a result, just one route is available between a node and its sibling nodes. The network partitioning may occur if the subsequent hop to the sibling node is not available.

S. Seungiae et al. [17] presents a novel DHT-based routing mechanism based on the last encounter routing (LER) for wireless networks. This LER-based mobile DHT leverages the mobility assisted milestone sharing to reduce the communication cost required for publish/lookup and membership management. The Motion-Mix DHT utilizes these milestones (position and time at which rendezvous happens) for introducing an effective lookup/publish operation to different data resources. In this way, the Motion-Mix DHT lookup, node joining, or leaving overheads are far less than other existing DHT-based routing approaches.

W. Hanno et al. [18] suggests a novel DHT-based scalable routing mechanism for wireless mesh networks (WMNs IEEE 802.11s) termed as the Mesh-DHT. The Mesh-DHT mainly focuses on utilizing the local information of nodes and provides efficient connectivity between them. In consequence, the routing overhead is decreased in a DHT-based logical network, and the number of transmissions is reduced as well. The Mesh-DHT provides better scalability and performance than the other approaches, but for a low mobility environment.

3. PROBLEM STATEMENT

In a DHT-based P2P overlay over MANETs, every OPP is assigned an identifier referred to as an ONL considering all the ONLs of its neighboring overlays participating peers (up to two-hop only). The OPP in the overlay P2P network over MANETs acquires its ONL from the overlay labeling zone (OLZ), which infers that every OPP is accountable for a segment of the overlay labeling zone termed as the overlay labeling zone segment (OLZS). Afterward, every OPP in the overlay topology stocks its ONL on another OPP referred to as the overlay anchor participating peer (OAPP). In addition to the ONL of the OPP, mapping knowledge (PNL-ONL pair along with OLZS) is stocked at the OAPP. An OPP, say 'W', executes a consistent hash operation on its MAC address (termed as physical network label (PNL)) to find out its corresponding OAPP. Subsequently, a specific hashed value is produced. The OAPP for the OPP 'W' is another OPP, say 'X', if the computed hashed value lies in the OLZS of the OPP 'X'. In other words, if the ONL of the OPP 'X' is nearest to the calculated hashed value, then OPP 'X' acts as the OAPP of the OPP 'W'. In data and control zones, the ONL and OLZS are exploited for efficient file sharing among the OPPs. The OAPP serves the crucial responsibility of stocking mapping knowledge (PNL-ONL pair along with OLZS) of other OPPs in the overlay topology. Therefore, OAPP, say 'a', of an OPP, say 'b', is inaccessible due to occurrence of the network partitioning, then the stocked mapping knowledge (SMK) at that OAPP is no more available. As a consequence, a huge loss of SMK is observed caused by network partitioning. Moreover, if any other OPP, say 'a', wants to communicate with another OPP, say 'b', then the lookup queries go in vain due to unavailability of the OAPP of the OPP 'b'. This problem persists till the OAPP specification of the OPP 'b'. Besides, the OPP 'b' refreshes the stocked SMK at the new OAPP. Because of these issues, increased lookup latency is observed. Hence, the P2P overlay protocol efficiency is significantly decreased.

The OPP should compute its ONL by considering the ONL of each neighboring physical overlay participating peer. It is a crucial step in correctly eliminating the mismatch issues among the physical network topology (PNT) and overlay network topology (ONT) as suggested in [19, 20]. In mobile ad hoc networks, two fundamental issues are present, i.e., dynamic mobility and restricted transmission zone. Owing to these two prominent issues in MANETs, the physical neighborhood connectivity information of an overlay participating peer is continuously fluctuating. So, every OPP in the overlay network topology needs to compute its ONL commensurate with the changing physical neighborhood connectivity information. As a consequence, increased computational, maintenance, control, and traffic overheads are observed. Furthermore, every OPP needs to refresh the SMK at the new OAPP. This phenomenon results in longer delays and increased traffic overheads at both the zones (control and data) in the refreshed overlay network label's recovery process.

In Figure 1, an example scenario is discussed to understand the identified problem. In Figure 1 (a), a physical network topology engaging both the OPPs and N-OPPs is depicted. Figure 1 (b) shows overlay network topology corresponding to the physical network topology. In this example scenario, the radio ranges of the overlay participating

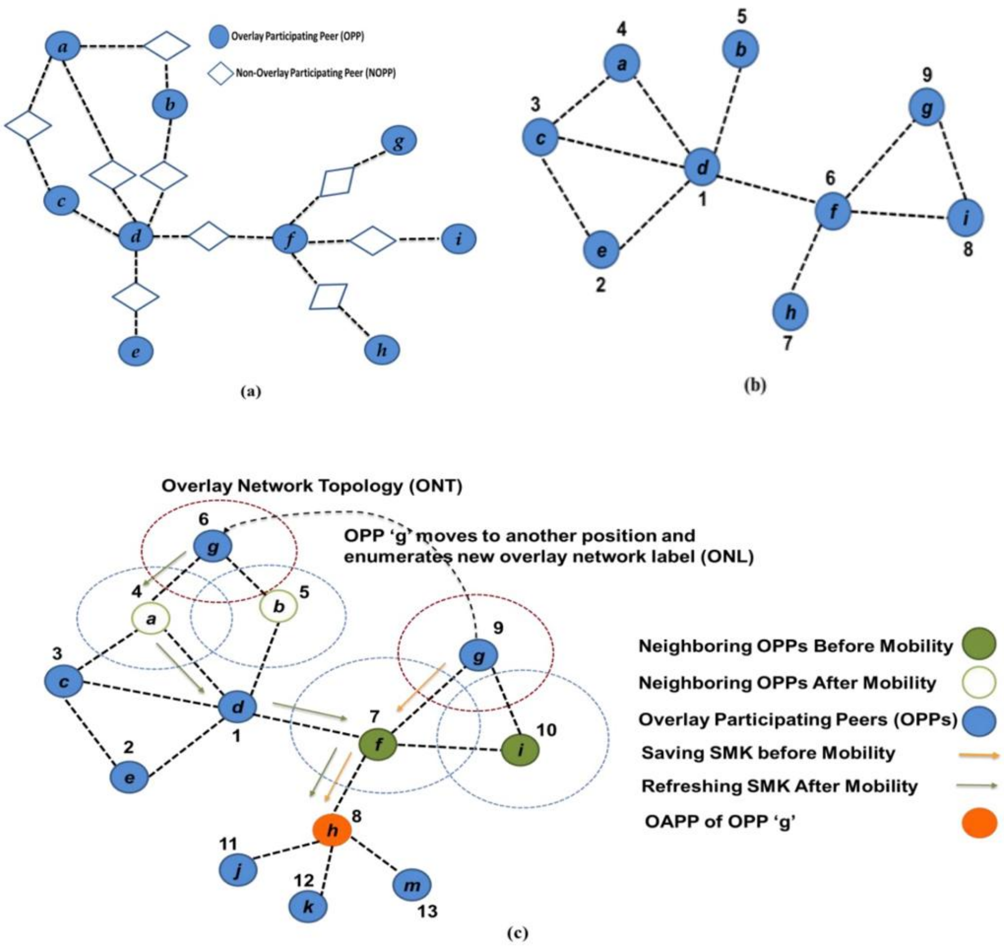

Figure 1: (a) Physical network topology, (b) Overlay network topology, (c) Along with transmission ranges, movement of overlay participating peer (OPP) 'g', Enumerating new overlay network label (ONL) & refreshing SMK at OAPP.

peers 'a', 'b', 'f', and 'i' are delineated by dark blue dotted circles. In addition, the radio ranges of the overlay participating peer 'g' before and after the movement are shown by dark red dotted circles (Figure 1 (c)).

Every overlay participating peer, in the P2P overlay topology, computes its ONL by considering the physical neighborhood connectivity knowledge (peers only) commensurate with the scheme 3DRP [20]. At present, in this example scenario, the ONL is considered as a numeric digit (1-20) to explicate the idea. In the example scenario (Figure 1), the overlay participating peer 'g' computes its ONL, i.e., 8 commensurate with the ONLs of all its neighboring physical overlay participating peers. The neighboring overlay participating peers of 'g' are 'f' and 'i'. The overlay participating peer, 'g', stocks its mapping knowledge, i.e., SMK at its OAPP (overlay anchor participating peer), i.e., the overlay participating peer 'h'.

This phenomenon is delineated in Figure 1 (c) (orange arrows towards 'h'). The overlay participating peer 'g' (ONL 8), departs the transmitting zones of the neighboring OPPs ('f' and 'i') and comes within the transmitting zones of another overlay participating peers (i.e., 'a' and 'b'). This phenomenon is illustrated in Figure 1 (c). It concludes that the overlay participating peer 'g' exists in a new spot and incorporates new neighboring overlay participating peers. At present, the neighborhood connectivity (participating peers only) of 'g' is entirely different ('a' and 'b') than before ('f' and 'i'). Because ONL in the P2P overlay is calculated, based on ONLs of its all neighboring physical overlay participating peers, thus, OPP 'g' computes the contemporary ONL by the latest physical neighborhood connectivity knowledge (overlay participating peers only). Accordingly, increased computational and traffic overheads are observed due to the overlay of participating peers' dynamic mobility and computing ONLs. They change their positions in accordance with new physical neighborhood connectivity knowledge (overlay participating peers only).

Afterward, OPP 'g' must refresh its stocked mapping knowledge (SMK) at its OAPP. The SMK consists of overlay network labels, physical network labels, and overlay labeling segments. In this case, the computed OAPP for the OPP 'g' is another OPP 'h' as presented in Figure 1 (c). Owing to ONL computation and the SMK refreshing processes, at the OAPP 'h', the computational, maintenance, control, and traffic overheads are sternly affected and tremendously exacerbated. It is important to remember that computational and traffic overheads are badly affected if an OAPP of a peer is unavailable due to its failure or movement to other locations in the network. Owing to this reason, an OPP must compute OAPP and need to stock the mapping knowledge at its new OAPP.

In high node mobility environments or scenarios, every OPP in the P2P overlay topology must reckon its ONL at frequent intervals because the neighborhood connectivity knowledge of an OPP in the physical topology is continuously changing. Consequently, OPPs update their OAPPs and refresh their stocked mapping knowledge at their latest OAPPs. During this process, the number of update messages (i.e., enumerating OAPPs and refreshing SMK) in the overlay P2P is increased. This phenomenon results in increased computational and traffic overheads at both the data and control zones.

Therefore, it is imperative to effectively address the identified problems in the P2P overlay over mobile ad hoc networks. In the current research work, a novel DHT-based 3D clustered P2P overlay protocol on top of a MANET is presented that works efficaciously at the application layer in the high mobility scenarios. The proposed P2P overlay protocol over MANETs presents an effective and efficient solution to cope with the mismatch issue and related identified problems in the high mobility scenarios. It offers exceptional performance in dealing with the mismatch issue among overlay and physical network topologies, increased computational, control, and traffic overheads compared with a competitive approach, 3DO [21] over MANETs. Moreover, 3DCOP presents the idea of utilizing overlay clusters together with the 3D overlay construction over MANETs. In this way, 3DCOP can significantly decrease the computational, control, and traffic overheads generated at every OPP in the P2P overlay over high mobility MANET environment. The proposed work may be considered a sound foundation for effective data dissemination in urban scenarios and define human behaviors by utilizing the internet of things, i.e., IoTs [22, 23] and big data analytics [24, 25].

4. PROPOSED SOLUTION

The details of the proposed solution to the identified issues are presented in the following subsections.

4.1. OVERLAY P2P CLUSTER (OPC) CONSTRUCTION

In the proposed scheme, all the one-hop OPPs reciprocate the HELLO notifications at a regular interval. These periodic HELLO notifications sent by the OPPs are utilized for overlay P2P cluster (OPC) construction. Consequently, the suggested novel scheme does not involve any additional traffic overhead for the construction of OPC. In this OPC construction process, the subsequent fundamental terminologies (Table 3) help perceive the proposed methodology predominantly. Table 4 depicts the notations and symbols utilized in the proposed P2P overlay scheme throughout the research article for better readers' convenience and understanding.

To cope with the identified problems discussed in the previous section, the proposed schemes present the concept of overlay clusters along with the 3D construction at the P2P overlay on top of MANETs for high mobility scenarios. The proposed 3D clustered overlay P2P protocol over a MANET works efficiently at the application layer by avoiding the identified issues in a high mobility environment. In the proposed methodology, OCL is designated by considering the highest OPP degree. The highest OPP degree means that an OPP has the highest number of the neighboring OPPs (one-hop only). In the proposed methodology, the ONL is only computed by the OCL. The calculation of the

Table 3: Fundamental Terminologies for Understanding the Proposed Methodology

Terminology	Description
HELLO Notification	Every OPP sends the HELLO notifications periodically to all the one-hop neighboring OPPs after a pre-established waiting time. The HELLO notification sent by an OPP incorporates the OPP degree, local neighborhood connectivity knowledge, and overlay P2P cluster adjoining information. In the local neighborhood connectivity knowledge, ONL of neighboring OPP and respective overlay cluster leaders are preserved. Besides, it comprises the neighboring OPP's responsibility either as an OCL or OCM in the OPC. The overlay P2P cluster adjoining knowledge contains the ONL of the neighboring OCL and information about the overlay gateway participating peer (OGPP) to create a linkage with the neighboring OCL.
Highest OPP Degree	The highest OPP degree means that the maximum number of one-hop neighboring OPPs are linked with that OPP. The HELLO notifications sent by each OPP are employed for the highest OPP degree calculation.
Overlay P2P Cluster	Overlay P2P cluster (OPC) consists of a set of OPPs (also called overlay cluster members (OCMs) in the proposed methodology). An overlay cluster leader (OCL) is picked from the participating OCMs by considering the highest OPP degree. The OCMs are at a distance (one-hop) from their OCL. It is important to mention that two neighboring OCLs do not come within a similar transmission zone. The recognition of OPC is done based on ONL allocated to OPC.
Overlay Cluster Member	OCM is the OPP that creates a linkage (one-hop) with the OCL in an overlay P2P cluster.
Overlay Cluster Leader	In each OPC, an OCL is chosen by considering the highest OPP degree. Every OPC carries only one OCL. The OCL of an OPC contains the knowledge of every OCM. A join timer of 3 seconds is set as per the proposed scheme. If an OCM in the cluster does not receive periodic hello messages from its OCL until 3 seconds, it will consider that its OCL has failed or moved out of the cluster.
Overlay Gateway Participating Peer	OGPP is the OPP that hears the HELLO notifications from two neighboring OCLs. OGPP obtains its ONL from the first OCL to whom it creates a linkage in the beginning.

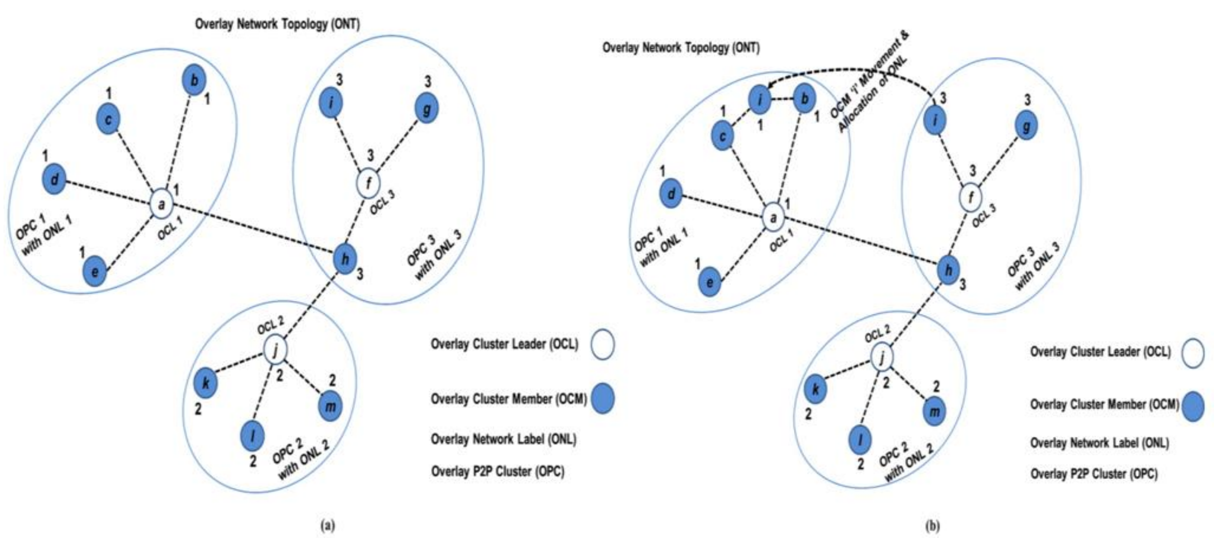

Figure 2: (a) Overlay Cluster with ONLs & (b) Movement of an OCM along with ONL allocation.

ONL by all the OPPs is not required in the proposed methodology. The ONL enumerated by the OCL are allocated to all the OPPs attached to it, are termed as overlay cluster members (OCMs). In 3DCOP, the ONL of the OCL is computed by considering all the neighboring OCLs as described in 3DcRP [9]. One of the prominent advantages of the proposed scheme is that if there is a change in the physical neighborhood connectivity of an OPP, say 'h'. The overlay participating peer 'h' does not require to reiterate the computation process for the ONL in case, 'h' resides in a similar OPC. Furthermore, if the OPP 'h' leaves OPC1 and becomes an OCM of a different OPC2 having distinct OCL, then the ONL is allocated to 'h' by the new OCL or by a new OCM. For the allocation of new ONL, the HELLO notifications are exploited by the OCL or an OCM.

In the proposed P2P overlay scheme, i.e., 3DCOP over MANETs, every OCL computes its ONL that recognizes every OPC in the overlay labeling zone. There is no need to calculate the ONL for every OCM separately. Instead, the OCL shares its computed ONL with its neighboring overlay cluster members (1-hop only). It infers that every OCM in an OPC exhibits the identical ONL shared by their respective OCL. Consequently, if an OCM leaves the first OPC1 and joins the second OPC2, then OCM does not need to recompute the ONL. In the existing DHT-based P2P overlay protocols over MANETs, an OCM requires calculating ONL every time it moves from one OPC1 to the second OPC2. However, in the proposed methodology, every OCM relocates itself with a sense of freedom in the overlay labeling zone. In the proposed scheme, the rule of the highest OPP degree is exploited for the selection of the OCL, which means that an OCL is chosen by considering the highest number of neighboring OCMs attached to it. In this way, the total number of overlay P2P clusters is considerably minimized. Additionally, every OCM exploits HELLO notifications for the creation of overlay P2P clusters. Consequently, the proposed methodology does not exhibit any additional traffic overhead. Some OCMs act as an overlay gateway cluster member (OGCM) in the proposed scheme, which lies within the transmitting zones of two or more than two OCLs. These OGCMs may be the OCMs that are in contact with an OCM of the next neighboring OCL.

Table 4: Notations & Symbols

Notations	**Description**
ONLi	Overlay network label of new overlay cluster leader i
L1x, L1y, L1z	Three ONL's tuples of the existing overlay cluster leader OCL1.
OLZS1x+	OLZS1x+ is the highest range of the OCL1's overlay labeling zone segment corresponding to the +x dimension.
NBrT	Neighborhood Table
DimOCLj	Dimension of Overlay Cluster Leader j
$\exists$	There Exists
$\in$	Belongs to
Σ	Sigma for Summation
Wij, Wik	Wij and Wik are the allocated weights by the OCLi to its one-hop neighboring OCLs.
Ljx, Ljy, Ljz	The equivalent ONL's tuples of the OCLi's neighboring OCLs in the x, y, and z dimensions, sequentially.
$\notin$	Does not belong to

To understand the proposed scheme, let us consider an example scenario in the Figure 2. Here, three OPCs 1, 2, and 3 are created over MANETs. The OCLs for these three OPCs 1, 2, and 3 are 'a', 'j' and 'f' sequentially. As per the proposed scheme, the computed ONL is considered the overlay network label of the OCL as depicted in Figure 2. One of the silent advantages of the proposed P2P overlay scheme may be identified as the lowest number of ONLs that need to be calculated. In the current scenario (Figure 2(a)), the total number of computed ONLs is minimized to 3. In consequence, the computational overhead at every OCM is significantly reduced. As a result, very little energy is utilized by the OCMs, which infers that the lifespan of every OCM is considerably extended. The proposed scheme facilitates the OCMs in their free movement. The OCMs do not require to calculate their ONLs as well. Additionally, refreshing the SMK is not required, resulting in substantial minimization of the computational overhead at every OCM. Thus, the lifespan of the active OCMs is notably extended. In Figure 2 (b), if an overlay cluster member, say 'i', moves from the OPC3 with ONL 3 and becomes an OCM of another neighboring OPC1 with ONL 1, then the OCM 'i' does not require to recompute the ONL. The new OCL 1 assigns the new OCM 'i' the same ONL it owns. The OCM 'i' acquires the ONL from the neighboring OCMs in a similar OPC1 by exploiting HELLO notifications. On the other hand, the OCL 3 (having ONL 3) and its OCMs do not require recomputing their ONLs because of OCM 'i' movement to another OPC 1.

4.2. OVERLAY PARTICIPATING PEER JOINING PROCESS

In 3DCOP, when an OPP participates in the P2P overlay network, it holds for a pre-established interval, say Ti, to hear HELLO notifications from the prevailing OCM or OCL. At the end of the pre-established waiting interval, every new OPP, say I, experiences the scenarios mentioned hereunder: Firstly, the newly joining OPP does not hear the HELLO notifications from the prevailing overlay participating peers in the P2P overlay network, then it considers itself as the pioneer OPP. Afterward, the new overlay participating peer builds a cluster and announces

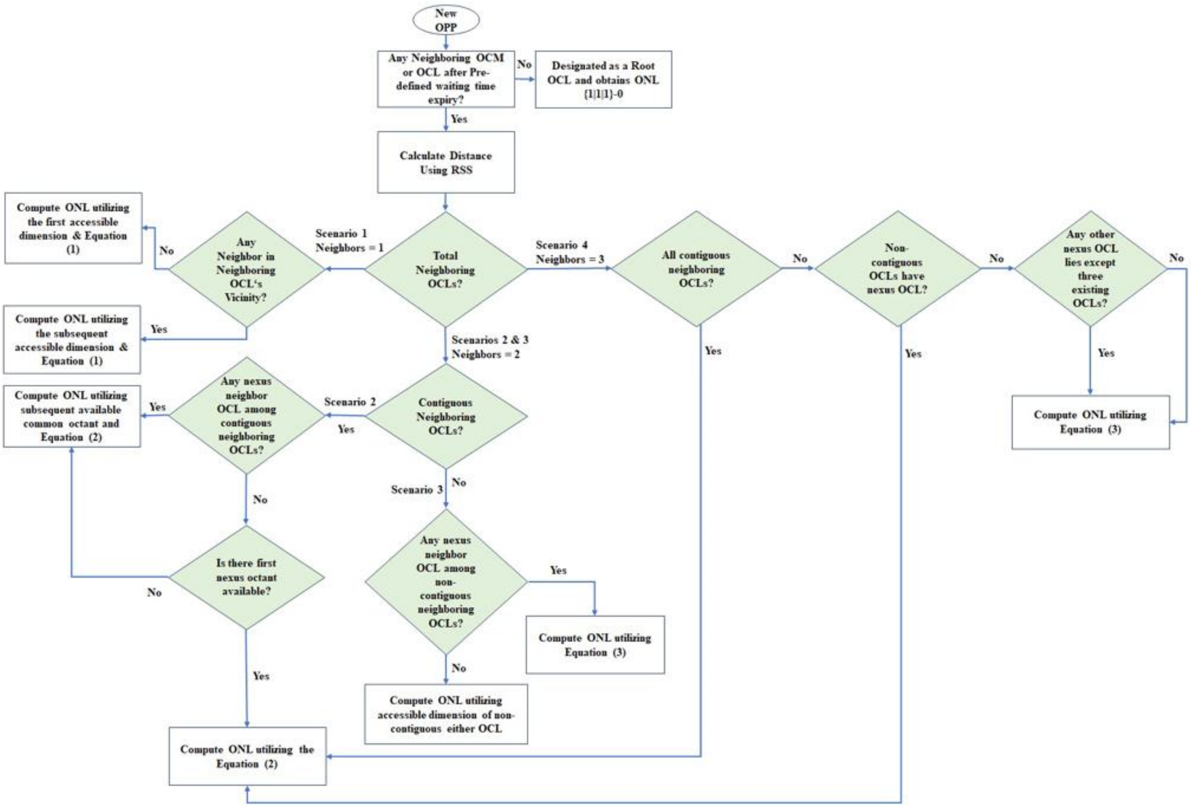

Figure 3: Flow Diagram of Joining Operations and ONL Computation.

itself as the OCL of that overlay P2P cluster. Subsequently, the newly created OCL obtains an overlay network label, i.e. $\{1|1|1-0\}$. Secondly, the new joining OPP hears HELLO notifications from the prevailing OCL, say OCL1, then the new OPP 'i' link itself with that OCL1. The new OPP 'i' acts as an OCM of the OCL1. The OPP 'i' does not require to calculate the overlay network label. The reason behind it is that the ONL of the OCL1 is allocated to all the connected OCMs of that overlay P2P cluster. It infers that every OCM exhibits the identical overlay network label as of its OCL in the specific overlay P2P cluster. Both OCL and OCMs share a similar overlay network label. Thirdly, the newly joining OPP 'i' hears HELLO notifications from the prevailing OCM, then the new OPP 'i' creates a new overlay P2P cluster and announces itself as the overlay cluster leader, say OCLi, of that newly formed overlay P2P cluster. Subsequently, the OCLi calculates the ONL by considering the 3DcRP [9] methodology as follows:

$$ONLi = \{L1x + (OLZS1x+)/4|L1y|L1z\} \tag{1}$$

In equation (1), L1x, L1y and L1z are the three ONL's tuples of the existing overlay cluster leader OCL1. OLZS1x+ is the highest range of the OCL1's overlay labeling zone segment corresponding to the +x dimension. The new overlay cluster leader OCLi will acquire 3/4 of the OCL1's OLZS1x+. By doing so, many new overlay cluster leaders can be accommodated in the overlay labeling zone. By the equation (1), the dimension for the new overlay cluster leader OCLi in the +x dimension of OCL1 will be 1. Besides, the overlay network labels for each new overlay cluster leader (OCLj or OCLk) will be 2 and 3, respectively, considering the subsequent accessible dimensions of the overlay cluster leader OCL1. By doing so, the physical intra-neighborhood connectivity knowledge of every OCL is adequately delineated in the overlay labeling zone.

3.1. If the new overlay cluster leader OCLi hears HELLO notifications from an existing overlay cluster leader OCL1, then the new overlay cluster leader OCLi exploits the subsequent convenient dimension of the existing overlay cluster leader OCL1's ONL for computation of its overlay network label ONLi. For example, if the new overlay cluster leader OCLi has only one neighboring OCL1, then the new OCLi acquires the subsequent convenient dimension $(+\times)$ of OCL1's ONL in the local 3D clustered overlay labeling zone (OLZ) of the neighboring OCL1. The convenient dimension is one of six accessible dimensions. These dimensions are besides - and + axes of local 3D clustered OLZS of the existing overlay cluster leader OCL1. The mathematical equation (1) is exploited by the new overlay cluster leader OCLi to calculate the overlay network label ONLi. The joining procedure described in case 3.1 is depicted in algorithm 1.

3.2. If the new overlay cluster leader OCLi hears the HELLO notifications from the two contiguous overlay cluster leaders OCL1 and OCL2, then the new OCLi finds the nexus overlay cluster leader among the contiguous overlay cluster leaders OCL1 and OCL2 for computation of ONLi. For this purpose, the OCLi considers the following two pre-defined conditions:

Algorithm 1: Joining Procedure (Scenario 1)

```
Require: In neighborhood table (NBrT) of OCLj, the neighborhood connectivity knowledge regarding the neighboring OCLi is stocked. Also,
  the hop distance to OCLi is obtained utilizing the routing agent, i.e., OLSR at joining OCLj.
  if ∃OCLi ∈ NBrT : (∃OCLm ∈ NBr(OCLi)) ≠ OCLj then
    DimOCLj ← NextAccessibleDimension(OCLm, OCLi)
  else
    DimOCLj ← firstAccessibleDimension(OCLi)
  end if
  ONLOCLj ← CalculateONL(OCLi, DimOCLj)
```

3.2.1. Suppose the new OCLi realizes the nexus overlay cluster leader's no existence among the contiguous overlay cluster leaders (OCL1 and OCL2). In that case, the new OCLi discovers the first nexus octant among the neighboring cluster leaders OCL1 and OCL2. Afterward, the new OCLi exploits the sign dimensions of that nexus octant for the calculation of ONLi. For this purpose, equation (2) is exploited by new OCLi. Eight similar octant zones are created as a division result of the three-axis planes. Each octant zone maintains similar coordinate indication from (-, -, -) to (+, +, +).

$$ONLi = \{\Sigma^n(OCLj = 1) \times Wij\Sigma^n(OCLk = 1)Wik \times Ljx|\Sigma^n(OCLj = 1) \times Wij\Sigma^n(OCLk = 1)Wik$$

$$\times Ljy|\Sigma^n(OCLj = 1) \times Wij\Sigma^n(OCLk = 1)Wik \times Ljz|\} \tag{2}$$

In equation (2), 'i' is the new joining overlay cluster leader i.e., OCLi. Also, $n \geq 2$ is the one-hop neighboring OCLs of the new OCLi. Moreover, Wij and Wik are the allocated weights by the OCLi to its one-hop neighboring OCLs, sequentially by utilizing the inverse distance function. For this purpose, OCLi exploits the OPP degree of its one-hop neighboring OCLs. Besides, Ljx, Ljy, and Ljz are the equivalent ONL's tuples of the OCLi's neighboring OCLs in the x, y, and z dimensions, sequentially.

3.2.2: On the other hand, if a nexus overlay cluster leader lies (suppose OCL3) among the contiguous overlay cluster leaders OCL1 and OCL2, then OCLi discovers the subsequent convenient nexus octant among the contiguous cluster leaders OCL1 and OCL2. Afterward, OCLi exploits the equation (2) for computation of its ONLi.

3.3. If the OCLi hears HELLO notifications from other two non-contiguous cluster leaders OCL1 and OCL2, then OCLi searches for a nexus overlay cluster leader among cluster leaders OCL1 and OCL2 by considering the following pre-established conditions:

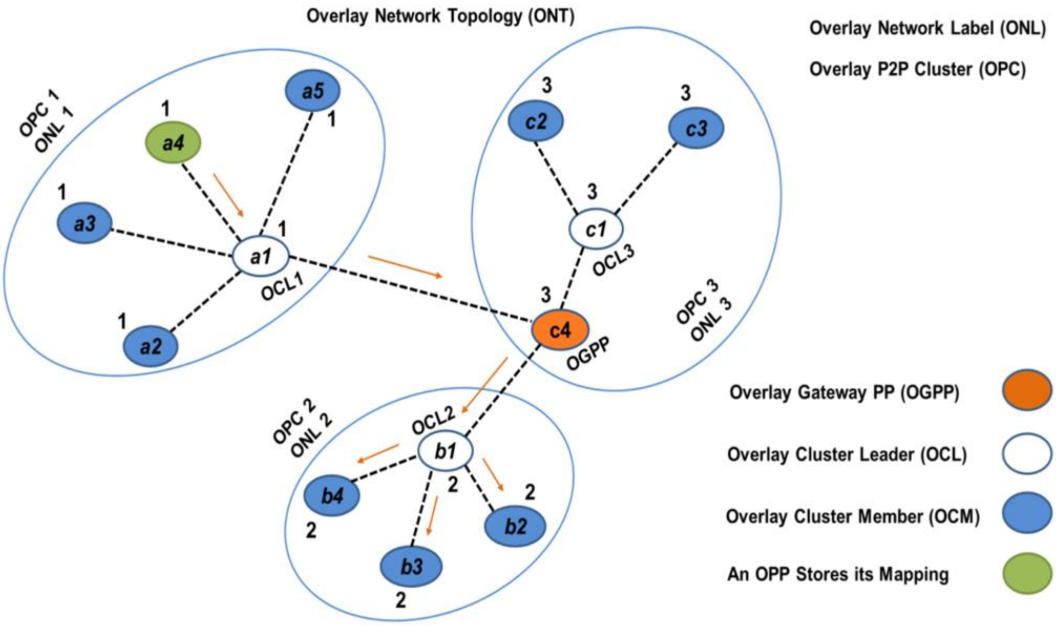

Figure 4: Stocking the Mapping Knowledge at OAPP

3.3.1. If a nexus overlay cluster leader lies among the two non-contiguous cluster leaders OCL1 and OCL2, then OCLi enumerates ONLi by exploiting the equation (3). For this purpose, every tuple of non-contiguous cluster leaders OCL1 and OCL2 are summed up by utilizing equation (3).

$$ONL_i = \{\Sigma^n(OCL_j = 1) \times L_j x | \Sigma^n(OCL_j = 1) \times L_j y | \Sigma^n(OCL_j = 1) \times L_j z\} \quad (3)$$

In equation (3), 'i' is the new overlay cluster leader i.e., OCLi. Also, $n \geq 2$ is the one-hop non-contiguous OCLs of the new overlay cluster leader, OCLi. In addition, Ljx, Ljy, and Ljz are the tuples of non-contiguous neighboring OCLs corresponding to each dimension. The ONL calculation in accordance with cases 3.2 & 3.3 is represented in algorithm 2.

3.3.2. If no nexus overlay cluster leader lies among the non-contiguous cluster leaders OCL1 and OCL2, then the new OCLi exploits the convenient dimension of either non-contiguous OCL1 or OCL2 for enumerating ONLi. For this purpose, OCLi considers the following pre-established guidelines:

i. The non-contiguous overlay cluster leaders (OCL1 or OCL2) having the highest number of OPPs in the overlay topology (highest peer degree).

ii. The non-contiguous overlay cluster leaders (OCL1 or OCL2) having greater convenient dimensions.

3.4. If OCLi receives HELLO notifications from other three contiguous or non-contiguous overlay cluster leaders OCL1, OCL2, and OCL3, then OCLi will enumerate its ONLi by considering the pre-established conditions as follows:

3.4.1. If the overlay cluster leaders OCL1, OCL2, and OCL3 are contiguous, then ONLi of OCLi will be enumerated as per the equation (2).

3.4.2. If the overlay cluster leaders OCL1, OCL2 are non-contiguous, then OCLi will check for a nexus (suppose OCL3) among the overlay cluster leaders (OCL1 and OCL2). Afterward, OCLi will enumerate ONLi by considering equation (2). On the other hand, if any other nexus lies except the overlay cluster leaders OCL1, OCL2, and OCL3 or no nexus exists, then OCLi will calculate ONLi by considering the equation (3).

The new overlay cluster leader considers the dimension (dim) value of the root overlay cluster leader for establishing its dimension (dim) value, which is carried out in all the three above scenarios (1-3). The root overlay cluster leader is the one that is a part of the ONL computation of the newly joined overlay cluster leaders. If a root overlay cluster leader is in the same direction, then the new overlay cluster leader establishes its dimension (dim) value similar to its root OCL. Conversely, the new overlay cluster leader establishes its dimension (dim) value to a root OCL with the highest peer degree. The new overlay cluster leader finds root OCLs having diverse dimension (dim) values. The ONL calculation in accordance with case 3.4, is represented in algorithm 3. In Figure 3, all the above-explained scenarios related to joining procedures and ONL calculations are described in a detailed flow diagram.

Algorithm 2: ONL Calculation (Scenarios 2 & 3)

Require: In the neighborhood table (NBrT) of OCLp, the neighborhood connectivity knowledge regarding the neighboring OCLi, OCLq is stocked. Also, the hop distance to OCLi and OCLq is obtained utilizing the routing agent i.e., OLSR at joining OCLp.
if $\exists OCLi, OCLp, OCLq \in NBrT(OCLp) : OCLp \in NBr(OCLi) and OCLi \in NBr(OCLq)$ **then**
  $OCTOCLp \leftarrow First(OCTOCLiOCLq)$
  if $\exists OCLj \in NBr(OCLi) and NBr(OCLq)$ **then**
    $OCTOCLp \leftarrow SubsequentNexusOctant(OCLi, OCLj, OCLq)$
  else
    $OCTOCLp \leftarrow FirstNexusOctant(OCLi, OCLq)$
  end if
else if $\exists OCLi, OCLq \in NBrTOCLp : OCLq \notin NBr(OCLi) and OCLi \notin NBr(OCLq)$ **then**
  $OCL_Contiguous \leftarrow false$
  if $\exists OCLj \in NBr(OCLi) and OCLj \in NBr(OCLq) where OCLj \neq OCLp$ **then**
    $ONLOCLj \leftarrow Calculate(OCLi, OCLq, OCL_Contiguous)$
  else
    $OCLpflag = Null$
    if $hopdistance(OCLi, OCLp) < hopdistance(OCLq, OCLp)$ **then**
      $DimensionOCLp \leftarrow SubsequentAccessibleDimension(OCLi)$
      $OCLpflag = OCLi$
    else if $hopdistance(OCLi, OCLp) > hopdistance(OCLq, OCLp)$ **then**
      $DimensionOCLp \leftarrow SubsequentAccessibleDimension(OCLq)$
      $OCLpflag = OCLq$
    else
      if $CountAccessibleDimension(OCLi) > CountAccessibleDimension(OCLm)$ **then**
        $DimensionOCLp \leftarrow SubsequentAccessibleDimension(OCLi)$
        $OCLpflag = OCLi$
      else
        $DimensionOCLp \leftarrow SubsequentAccessibleDimension(OCLq)$
        $OCLpflag = OCLm$
      end if
      $ONLOCLp \leftarrow CalculateONL(OCLpflag, DimensionOCLp)$
    end if
  end if
end if

Algorithm 3: ONL Calculation (Scenario 4)

Require: In neighborhood table (NBrT) of OCLp, the neighborhood connectivity knowledge regarding the neighboring OCLi, OCLq, and OCLh is stocked. Also, the hop distance to OCLi, OCLq, and OCLh is obtained utilizing the routing agent, i.e., OLSR at joining OCLp.
$OCLCommon \leftarrow false$
if $\exists OCLi, OCLq, OCLh \in NBrTOCLp : OCLq \in NBr(OCLi), NBr(OCLh) and OCLi \in NBr(OCLq), NBr(OCLh) and OCLh \in NBr(OCLi), NBr(OCLq)$ **then**
  $ONLOCLp \leftarrow CalculateONL(OCLi, OCLq, OCLh)$
  return
else if
$OCLi \in NBr(OCLq), NBr(OCLh) and OCLq \notin NBr(OCLh) and OCLh \notin NBr(OCLq) or OCLq \in NBr(OCLi), NBr(OCLh) and OCLi \notin NBr(OCLh) and OCLh \notin NBr(OCLi) or OCLh \in NBr(OCLq), NBr(OCLi) and OCLq \notin NBr(OCLi) and OCLi \notin NBr(OCLp)$ **then**
  $OCLCommon \leftarrow true$
  $ONLOCLp \leftarrow CalculateONL(OCLi, OCLq, OCLh)$
  return
else
  $ONLOCLp \leftarrow CalculateONL(OCLi, OCLq, OCLh, OCLCommon)$
end if

4.3. OVERLAY ANCHOR PARTICIPATING PEER COMPUTATION

In a DHT-based P2P overlay over MANETs, if a source overlay participating peer (SOPP) intends to send a file to a destination overlay participating peer (DOPP), then it first needs to compute the overlay anchor participating peer (OAPP) for the DOPP. An OAPP is a participating peer held responsible for stocking the mapping knowledge for the other overlay participating peer (s). The mapping knowledge stocked at the OAPP contains PNL (MAC address), ONL, and OLZS information of an overlay participating peer. It is important to mention that an OAPP can behave as an anchor for one or more than one OPPs. The OPP, say 'X', implements a consistent hashing operation on its PNL (MAC address) to reckon its OAPP. The calculated hashed value, say h(X), is acquired from the similar overlay labeling zone from where the ONLs of all the OPPs are taken. The OPP whose ONL is nearest to the computed hashed value h(X) becomes the OAPP, say 'W', of the OPP 'X'. To stock the mapping knowledge (PNL-ONL set, OLZS) to the OAPP 'W', the OPP 'X' instigates the mapping knowledge store (MKS) notification heading to the computed hashed value h(X). In the proposed 3D clustered P2P overlay over MANETs, every OPP preserves the local neighborhood connectivity knowledge up to two-hop. For this purpose, periodic HELLO notifications are exploited. In two-hop local neighborhood connectivity knowledge, an OPP contains OCMs, OCL, and OGPP to access the OCLs in the local neighborhood connectivity (two-hop) as suggested in CBRP [21]. As per the proposed scheme, the MKS is equally updated at both the OCL and all other OCMs overlays P2P cluster. The MKS notification by the newly joined OPP 'X' is forwarded by considering the following scenarios:

1. If the ONL of the newly joined OPP 'X' is nearest to the calculated hashed value resides in the forwarded MKS notification, then OPP 'X' behaves itself as the OAPP for OPP 'X'. In this scenario, the MKS is stocked at the OPP 'X' that behaves as OAPP for OPP 'X'. The OPP 'X' then forwards the MKS to its overlay cluster leader, say OCL1, that stocks the MKS and forwards it to all the one-hop OCMs in that overlay P2P cluster. All OCMs stock a replica of the forwarded MKS as well.
2. Conversely, if the ONL of the overlay cluster leader, say OCL2, in the two-hop local neighborhood connectivity is nearest to the computed hashed value h(X), then OCL2 behaves as the OAPP of the OPP 'X'. The OPP 'X' sends the MKS notification to the OCL2 by exploiting the closest overlay gateway participating peer towards OCL2, as suggested in CBRP [21]. There are following two sub-scenarios:
   i In case, if the OAPP is an OCM, say 'Y', then the OCM 'Y' stocks the MKS and sends it to its overlay cluster leader, say OCL3, that stores the forwarded MKS. The OCL3 sends the MKS to all its one-hop OCMs that stock the forwarded MKS as well as a replica.
   ii In case, if OAPP is an overlay cluster leader, say OCL4, then OCL4 stocks the MKS and forwards it to all the one-hop OCMs in its overlay P2P cluster. All the one-hop OCMs stock the MKS forwarded by their OCL4 as a replica as well.

Consider the example scenario given in Figure 4. In this example scenario, the newly joined OPP 'a4' of OPC1, having overlay cluster leader, say OCL1, with ONL 1 stocks the mapping knowledge (PNL-ONL set, OLZS) at its OAPP. For this purpose, the OPP 'a4' implements a consistent hashing operation on its physical network label. The calculated hashed value is 2. The OPP 'a4' sends the MKS notification to its overlay cluster leader OCL1 heading to OCL2 with ONL 2. The OCL1 sends the received MKS notification towards the OGPP 'c4' with ONL 3 heading to OCL2 with ONL 2. The OGPP 'c4' sends the received MKS notification towards OCL2 'b1' with ONL 2. The OCL2 'b1' with ONL 2 is the nearest to the enumerated hashed value that resides in the MKS notification. The OCL2 stocks the received hashed value in the MKS notification and forwarded the MKS notification towards all the one-hop overlay cluster members. All the one-hop OCMs stock the hashed value received in the MKS notification as a replica.

4.4. FILE RETRIEVAL PROCESS

The source SOPP, say 'M', requires the ONL of the DOPP, say 'N', to successfully forward the data packet to DOPP. For this purpose, the SOPP 'M' executes a consistent hash operation on the physical network label of the DOPP 'N'. As a result, the SOPP 'M' obtains the ONL of DOPP's OAPP. The OAPP of DOPP 'N' is another OPP,

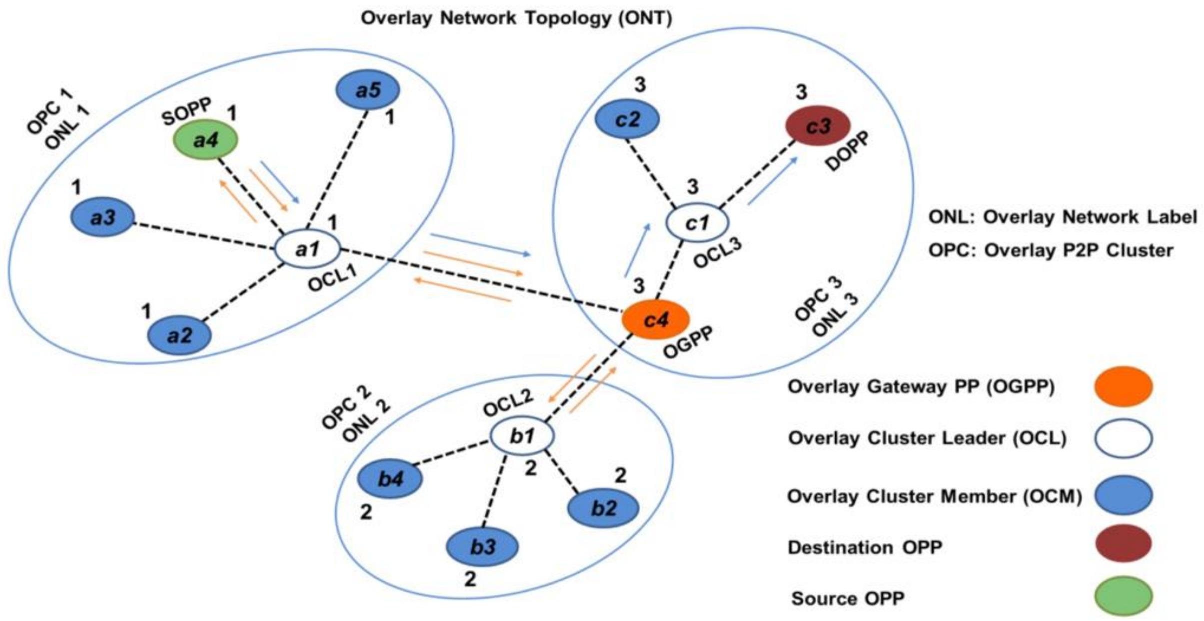

Figure 5: File Retrieval Procedure in 3DCOP over MANETs

say 'L' belongs to OPC 1. The SOPP 'M' forwards the mapping petition notification (MPTN) to the OAPP 'L' to recover the DOPP 'N' overlay network label. The PNL and ONL of the SOPP 'M' are attached to the MPTN. The forwarding of the MPTN is identical to the SMK notification. The only difference is in the scenario where the MPTN receives at an OCM, say 'K'. The OCM 'K' is an overlay cluster member of the OPC 1. The OCM 'K' sends the ONL of the DOPP 'N' to the requesting SOPP 'M' in mapping reply notification (MRN). The MRN is forwarded to the SOPP 'M' by exploiting the ONL of SOPP 'M' resides in MPTN. Eventually, the MRN receives at the overlay P2P cluster of the SOPP 'M'. Then, the OCL of that OPC exploits the PNL of the SOPP 'M' for forwarding the received MRN. It infers that within the overlay P2P cluster, the proposed methodology exploits the physical network label of the OCMs for communication. Within the OPC, the ONL cannot be utilized as all the OCMs in that OPC exhibit the identical ONL. Afterward, the SOPP 'M' forwards the data packet towards the DOPP 'N' by exploiting the received ONL of DOPP 'N' in the received MRN. The SOPP 'M' appends both the ONL and PNL of the DOPP 'N' with the data packet. The data packet is sent identically as SMK forwarding by utilizing the ONL of DOPP 'N'. Within the OPC of DOPP 'N', PNL of DOPP 'N' is exploited to forward the data packet to DOPP 'N'.

The example in Figure 5 explains the file retrieval procedure in detail. The SOPP, say 'a4', of OPC1 having ONL 1 (with OCL1) forwards a data packet to a DOPP, say 'c3', of OPC3 having OCL3 with ONL 3. For this purpose, the SOPP 'a4' needs to acquire the mapping knowledge of the DOPP 'c3'. The mapping knowledge of DOPP 'c3' is stocked at the OAPP of DOPP 'c3'. The SOPP 'a4' implements a consistent hashing operation on the PNL of the DOPP 'c3'. As a result, a hashed value is obtained. The MPTN consists of the computed hashed value as destination ONL for mapping knowledge recovery of DOPP 'c3' from the OAPP of 'c3'. Now, the SOPP 'a4' forwards the MPTN towards the OAPP of 'c3'. The MPTN is sent identically as of SMK forwarding towards the OAPP of DOPP 'c3'. When the MPTN reaches the OAPP of DOPP 'c3', then OAPP, say 'b1', in OPC2 with ONL 2 sends the acknowledgment to the SOPP 'a4' by forwarding the MRN. In the sent MRN, the stocked mapping knowledge (PNL-ONL set, OLZS) of DOPP 'c3' is included. The MRN is then forwarded towards the SOPP 'a4' that resides in OPC1 as an OCM. The MRN is sent identically as of SMK forwarding. The SOPP 'a4' forwards the data packet towards the DOPP 'c3' by exploiting ONL 3 and PNL of DOPP 'c3' received in the MRN. The data packet is

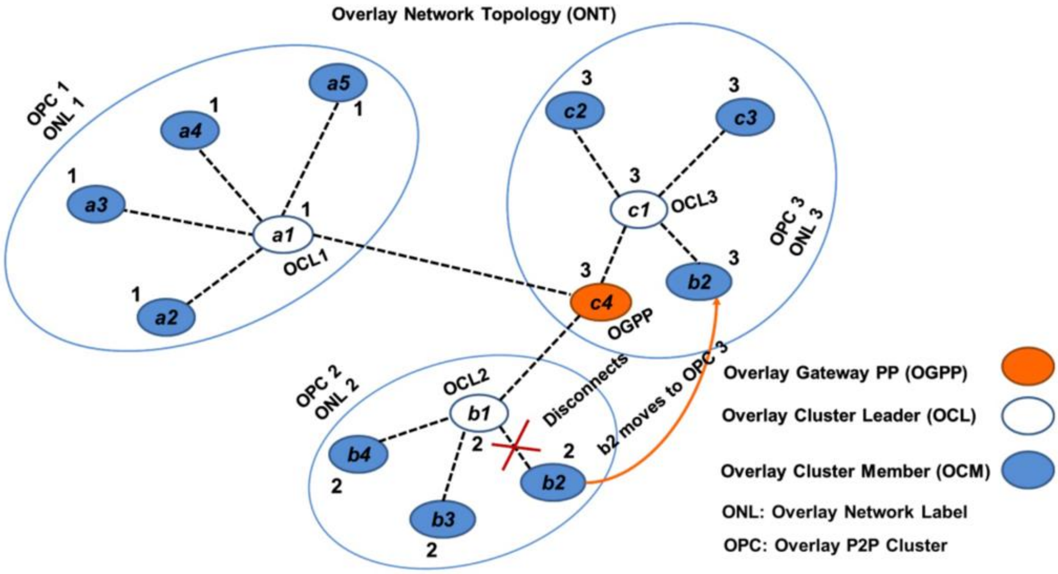

Figure 6: OPP Movement and Allocation of New ONL

eventually sent towards the destination OPC3, where the DOPP 'c3' resides as an OCM. The received data packet is forwarded by the OGPP 'c4' towards the OCL3 (DOPP 'c3' is an OCM of OCL3). Within the OPC3, the PNL is exploited to forward the received data packet towards the DOPP 'c3' by the overlay cluster leader OCL3. Within the OPC, the overlay network label cannot be exploited because all the OCMs in that OPC have the identical ONL as of OCL of that OPC. The OGPP is exploited if the OCL of an OPC moves or fails for communication among the SOPP and DOPP.

4.5. UPDATE PROCEDURE

The proposed DHT-based P2P overlay scheme over MANETs (i.e., 3DCOP) exploits the overlay clustering concept together with the 3D overlay zone to offer the resilient path choices for forwarding the stocked file from the SOPP to the DOPP as suggested in 3DcRP [9]. In the proposed scheme, the OCL is chosen by considering the highest number of overlay participating peers or OCMs attached to it. The OCL holds its responsibility as the leader, although it loses the highest number of peers attached to it. It means that the leader keeps its position as the leader, even the OPP degree of an OCM becomes higher than the leader. The OCL of an overlay cluster alters only in case of its movement to another cluster or failure of the OCL. A backup path is always accessible by the proposed methodology in case the OCL and OGPP moved or failed. If the OCL or the OGPP movement to another overlay cluster or failure occurs, then the suggested P2P overlay scheme offers consistency by minimizing the traffic overhead. In the DHT-based P2P overlay over MANETs, the overlay network arrangement constantly alters because of the overlay participating peers' dynamic mobile nature. The proposed DHT-based P2P overlay scheme over MANETs offers great resiliency in computing the ONL of an OPP in case of the OCL movement or its failure. The OPP realizes the link breakage with the OCL in case; the OPP does not hear the HELLO notifications from the OCL. In the proposed P2P overlay scheme over MANETs, an interval If (interval failure) or interval Im (interval mobility) is preserved at each OPP. An OPP, say 'a', hold for an interval If (interval failure) so that it may re-establish its linkage with its OCL. Although the OPP 'a' is free to establish the linkage with the OCL in the neighborhood connectivity. The OPP 'a' may shape a new overlay P2P cluster commensurate with the proposed scheme. In both the scenarios (joining a new OCL or shaping a new OPC), the OPP 'a' is allocated a new ONL. The OPP 'a' preserves the previous ONL

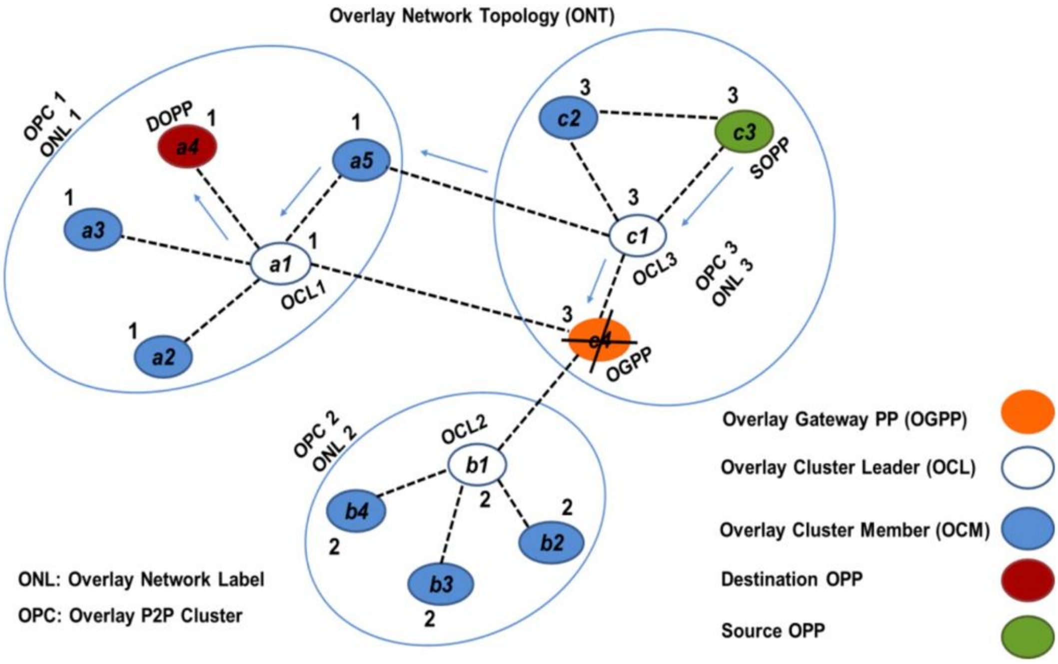

Figure 7: New Path Selection in Case of OGPP Failure

for a specific time duration to effectively address the in-transit file retrieval requests.

In the Figure 6, an OCM 'b2' does not hear any HELLO notifications from its overlay cluster leader OCL2 'b1' with ONL 2. After the waiting interval's expiry, the OCM 'b2' establishes the linkage with another neighboring OPC 3 after hearing the continuous HELLO notifications from the OCL3 'c1' with ONL 3. Afterward, 'b2' becomes an OCM of the OPC 3 member. The OCL3 of OPC 3 with ONL 3 allocates a similar ONL (i.e., 3) to the newly joined OCM 'b2' under the proposed methodology.

In the Figure 7, an example scenario discusses the failure of a transitional OGPP and picking up another best available path procedure following the proposed scheme. In Figure 7, an OCM, say 'c3' with ONL 3, intends to forward the file towards another OCM, say 'a4', having ONL 1. The route adopted by the transmitted file is c3-c1-c4-a1-a4, as presented in Figure 7. At present, if the transitional OCM, say 'c4', becomes unavailable because of its failure, then the OCM 'c3' forwards the file towards the another OGPP of OPC 1 via OCL3. Here, OGPP of OPC 1 is an OCM, say 'a5' having ONL 1. Afterward, the OCM 'a5' forwards the received file towards its OCL1 'a1' having ONL 1. The OCL1 sends the received file towards the DOPP 'a4'. For this purpose, the OCL1 exploits the physical network label of the DOPP 'a4'.

5. PERFORMANCE ANALYSIS

We use the network simulator NS-2 (version 2.35) to execute each simulation to assess the performance of the proposed P2P overlay scheme, an open-source discrete-event network simulator. To simulate IEEE 802.11, the standard values for both the physical and link layers are utilized with Two-Ray Ground as the propagation model. Table 5 presents the simulation parameters. The proposed P2P overlay protocol, 3DCOP, is compared with a competitive overlay scheme, i.e., 3DO [19] in the classification of P2P overlay schemes over MANETs. 3DO overlay P2P protocol enables the three-dimensional construction to deal with the mismatch issue among the physical and overlay network topologies. Moreover, 3DO offers considerable resiliency against node failures or movement scenarios. In 3DO, the participating peer computes its ONL by utilizing the ONLs of all its neighboring participating peers in the network, which results in an increased computation, control, and traffic overheads. On the other hand, in the proposed P2P overlay scheme, i.e., 3DCOP, the overlay cluster leader is responsible for allocating the ONL to the newly joining participating peers in its overlay P2P cluster. As a result, the computational, control, and traffic overheads are greatly minimized.

In order to perform the simulations, we specify the size of the playground area as 1000 m × 1000 m. The maximal transmitting range of a participating node is defined as 50 m. The transmitting range of participating nodes is chosen to spans through all the participating nodes at a 2-hop distance. The proposed P2P overlay scheme, i.e., 3DCOP, utilizes the HELLO notifications periodically exchanged among the participating peers to maintain the connectivity. A network simulation scenario is created similar to a real one that follows a uniform distribution. The simulations are implemented, having motion patterns produced by utilizing four distinct node-moving speeds (7, 13, 19, and 25m/s) as depicted in Table 5 below. The reason behind the restriction of node speed to 7 to 25m/s is that the mobile ad hoc network is not sustainable to intensely high or less speed scenarios. The speed values are uniformly selected, ranging from 7m/s to 25m/s. To ascertain the physical network connectivity, we utilized BonnmotionV2 to create the mobility scenarios as per the random way point (RWP) model. It is utilized by the wireless networking research community more often for accurate performance evaluation of wireless ad hoc networks owing to its swift execution and convenience. In 3DCOP, the underlying mechanism, OLSR, is used. Further, each OPP involves sharing ten distinct files. In the network, the file discovery procedure is started instantly for 100 files. The effectiveness of overlay maintenance and file discovery mechanisms is thoroughly assessed. For this purpose, the values of different parameters are changed as per the requirements. A parameter, peer ratio, is discussed as well in detail. This parameter, i.e., the peer ratio, is the ratio of OPPs to the total number of mobile nodes in the physical network topology. The random traffic pattern is being utilized as a traffic model. Constant Bit Rate (CBR) flows on top of the UDP protocol are utilized for shaping the data traffic. A linked network construction for both 3DO and 3DCOP is supposed. We performed 10 runs per scenario, and the average simulation outcomes are represented in the form of graphs. The simulation time is set as 500 seconds. The dynamic mobility of an OPP is analyzed by changing the average OPP speed ranging from 7 m/s to 25 m/s. To evaluate the effectiveness of 3DCOP, the following four performance parameters are tested against the changing size of the network.

Table 5: Simulation Parameters

Parameter	**Value**
Playground Size	[$1000m \times 1000m$]
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	[$7m/s - 25m/s$]
Traffic Model	Random Traffic Pattern
Mobility Model	Random Way Point
Radio Propagation Model	Two Ray Ground

- Routing Traffic Overhead (RTO): The execution of lookup requests routing for data packets in the network, the total number of control overhead packets exploited by the P2P protocol, is referred to as the routing traffic overhead.

- False-Negative Ratio (FNR): The meantime duration started with the file lookup request until meeting the first response from the destination. The minimized false-negative ratio for an overlay P2P protocol ascertains the maximal ingresses to the files.

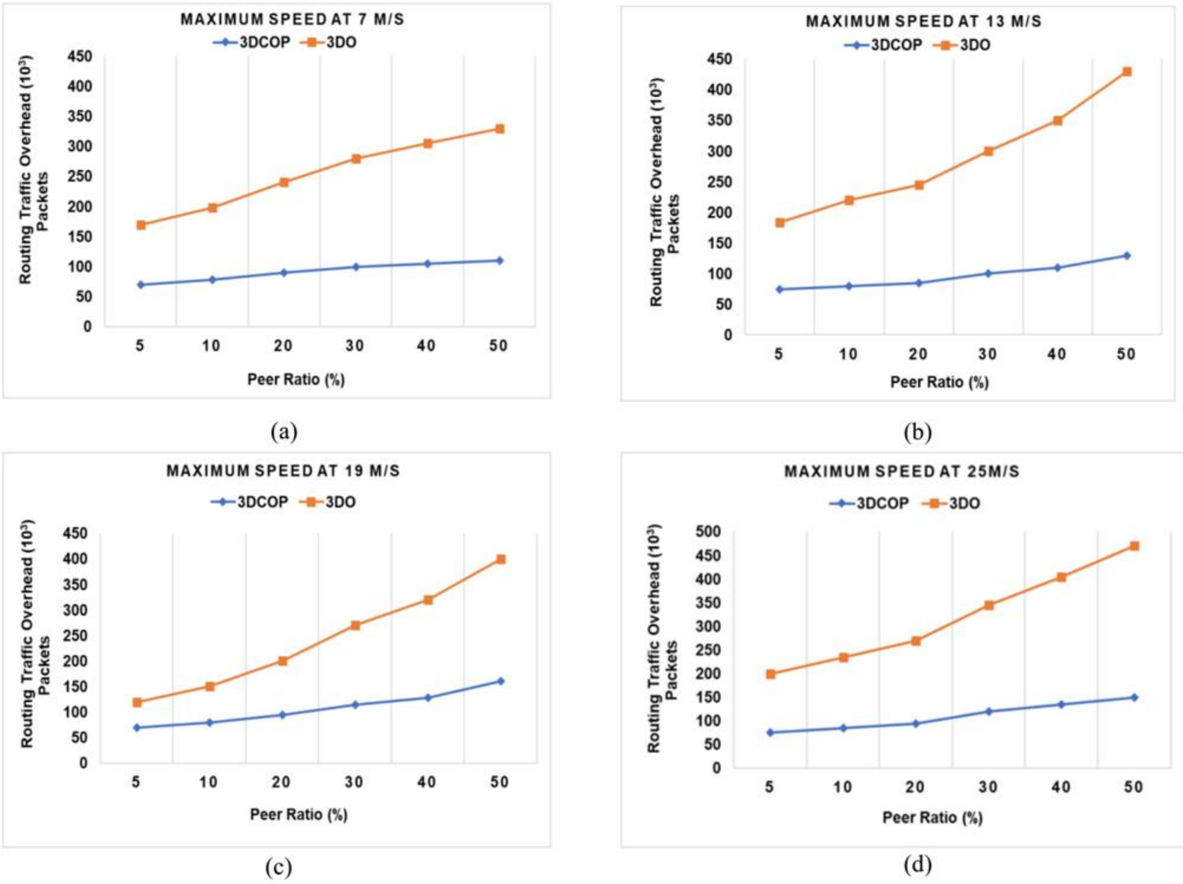

Figure 8: Routing Traffic Overhead vs. Peer Ratio at Different Node Speeds

- Path-Stretch Ratio (PSR): It is the accessible route length in the overlay P2P network topology to the smallest route in physical network topology among the OPPs. Through PSR, the P2P overlay protocol's strength can be efficiently assessed since the PSR value defines the capability of the P2P overlay protocol for identifying the smallest accessible route to a destination OPP in the P2P overlay network.
- Average File Discovery Delay: The delay is generated because of unanswered lookup requests for the destination OPP to the total number of initiated lookup requests in the physically connected network.

5.1. ROUTING TRAFFIC OVERHEAD (RTO)

In this segment, the operation of 3DCOP and 3DO is discussed, considering the routing traffic overhead computed against changing OPP moving speeds and ratios. The fundamental purpose is to evaluate the scalability of the 3DCOP and 3DO, considering the routing traffic overhead. Owing to the dynamic topology, the additional routing traffic overhead is observed if the speed of OPP rises. The reason behind traffic overhead rise is the adaptation of the overlay network construction by the physical network neighborhood connectivity knowledge. The routing overhead raises in case the OPPs are out of zone or existence of broken paths. It is observed that the routing overhead is badly affected by 3DO than 3DCOP when the speed of OPP rises. This phenomenon is delineated in Figure 8. In different scenarios, the speed of the OPPs is changing from 7m/s to 25m/s. For these scenarios, 3DCOP performs far better than 3DO concerning the routing traffic overhead.

Figure 8 depicts that 3DCOP significant minimizes the routing traffic overhead in comparison to 3DO against different OPP ratios as 30% to 50%, 32% to 56%, 41% to 60% and 40% to 53% at OPP speeds 7m/s, 13m/s, 19m/s, and 25m/s, respectively. 3DCOP performs significantly better than 3DO against the varying OPP speeds. The reason behind it is, 3DCOP creates and retains the overlay construction that exactly preserves the physical neighborhood connectivity knowledge. Consequently, redundant longer paths are avoided. Besides, 3DCOP proposes an efficient replication methodology for effectively minimizing the routing traffic overhead in scenarios where an overlay anchor participating peer failure or movement occurs.

In 3DO, if a participating peer moves to another location, and its neighborhood connectivity knowledge changes, then it should compute its overlay network label again commensurate with the new neighborhood connectivity. This phenomenon is the fundamental reason for the significant rise in the routing traffic overhead for 3DO. But, in 3DCOP, when an OPP moves from cluster 1 to cluster 2, it is not required to recompute its overlay network label. The reason behind this is the cluster head of cluster 2 allocates the similar ONL that it owns to the newly joining cluster member. This phenomenon substantially minimizes the routing traffic overhead. Routing traffic overhead is increased in case the OPP ratio rises. This phenomenon is the main reason for the dropping of packets and contention events in the network. In the 3DO P2P overlay protocol, additional routing traffic overhead is generated compared to the proposed scheme 3DCOP when the OPP ratio rises against different OPP speeds. The fundamental reason behind this significant rise in routing traffic overhead for 3DO is the mismatch between the physical and overlay network topologies.

5.2. FALSE-NEGATIVE RATIO (FNR)

In the current segment, the operation of 3DCOP and 3DO is assessed, considering the false-negative ratio against different OPP speeds and ratios. This assessment's fundamental purpose is to ascertain the comparison of unanswered lookup requests for the destination OPP in the physically linked network to the number of lookup requests generated in the beginning. In Figure 9, FNR for both 3DCOP and 3DO is demonstrated in the case of increased OPP speeds and ratios. It is depicted in Figure 9 that, in comparison to 3DCOP, the impact of increased OPP ratio on the FNR is worst for 3DO. The false-negative ratio for the existing 3DO protocol compared to the proposed protocol 3DCOP rises against different OPP ratios 40% to 52%, 44% to 51%, 41% to 53% and 43% to 54% at OPP speeds 7m/s, 13m/s, 19m/s, and 25m/s, respectively. In the high mobility environment, the topology of the overlay network is altered more often. This frequent alteration in the overlay network topology is because of the high OPP moving speeds.

Consequently, a higher delay is observed, which is because of the contention phenomenon produced in the case of the information retrieval process and the rise in collisions of packets in the network. In high mobility scenarios, the dropping of packets is common. This occurrence emerges as many routes become inaccessible in the network, and likewise, a smaller number of messages are exchanged among the OPPs. The proposed P2P overlay protocol effectively eliminates the mismatch issue among the physical and overlay network topologies. One of the reasons is the resilience of the overlay construction provided by the 3DCOP, and another cause is the cost-effective lookup operation proposed by 3DCOP. Resultantly, the overhead is significantly minimized in both the data and control zones. Due to this phenomenon, stocked files are conveniently accessible; besides, 3DCOP offers an effective replication mechanism. This replication mechanism performs better than 3DO when a major OAPP failure occurs or moved to another location in the network. To sum of, the proposed mechanism 3DCOP comprises considerable minimized traffic overhead that results in reduced FNR, as shown in Figure 9.

5.3. PATH-STRETCH RATIO (PSR)

In this segment, the efficacy of routes to the destination is assessed by considering the number of hops. The comparison is performed based on the path-stretch ratio for both the 3DCOP and 3DO. PSR is computed by performing a comparison among the lengths of physical and overlay networks' routing paths. PSR serves as one of

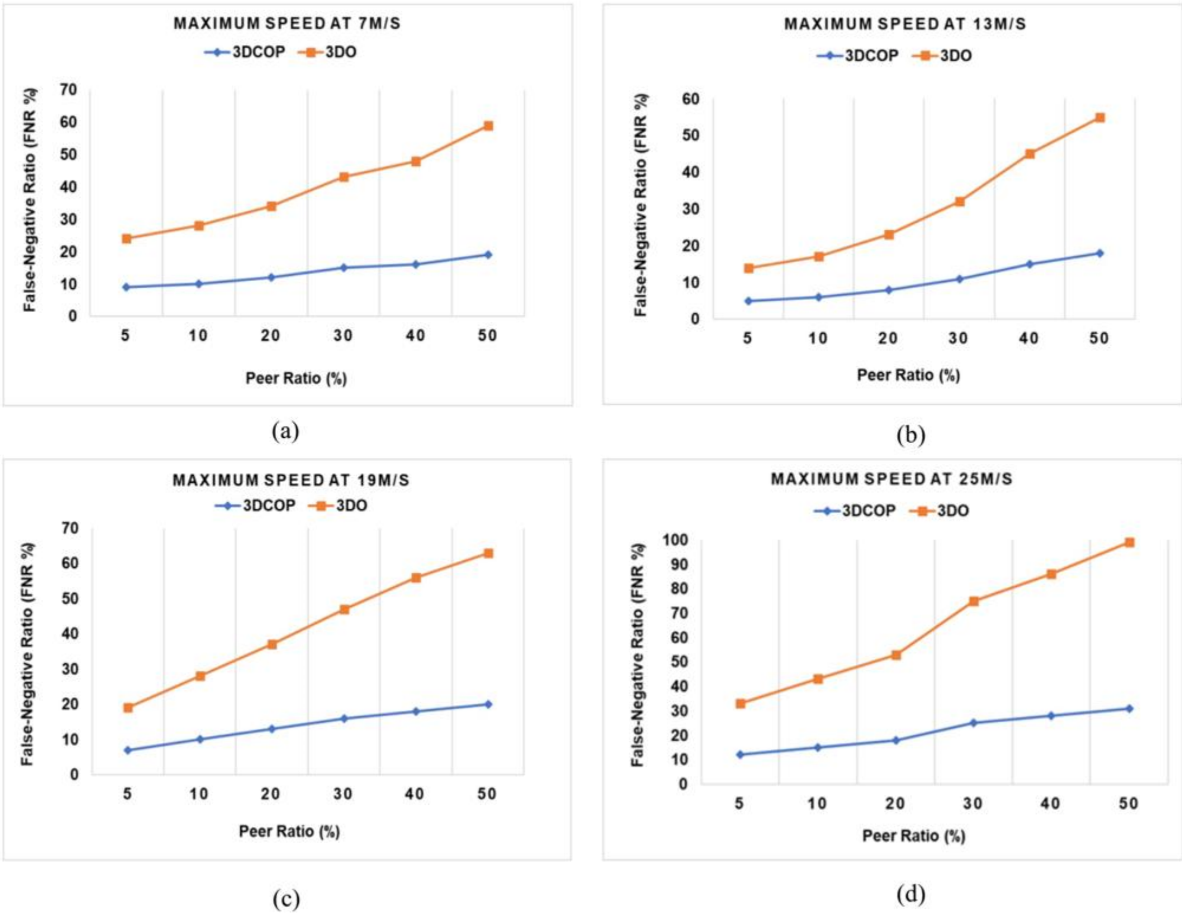

Figure 9: False-Negative Ratio vs. Peer Ratio at Different Node Speeds

the key factors for analyzing the mismatch issue between the physical and overlay network topologies. The efficiency of the network is significantly enhanced by minimizing the PSR. The minimized PSR plays a critical role in lowering the excessive number of transmissions in the high mobility network environment. In Figure 10, PSR for both 3DCOP and 3DO is demonstrated versus the OPP ratio. The mean PSR is minimized for the proposed methodology 3DCOP in comparison to 3DO. It is delineated in the simulation results that PSR significantly rises for 3DO. It happens in a situation when a newly joining OPP (S) receives HELLO messages from two neighboring OPPs (S1, S2) that are contiguous but possess distinct dimensions.

In the Figure 10, a notable rise is noticed in PSR for 3DO in comparison to 3DCOP from 12% to 23%, 15% to 25%, 17% to 26% and 18% to 32% against the OPP changing speeds 7m/s, 13m/s, 19m/s and 25m/s respectively. As depicted in Figure 10, the mean PSR for 3DO is somewhat influenced by the OPP ratio. Additionally, the path-stretch ratio value for 3DO is not maintained at zero all the time. It infers that no shortest route is always possible among the source OPP and a requesting OPP in the physical topology. The reason behind this phenomenon lies in routing provided by OLSR (i.e., due to the specification of the multipoint relay).

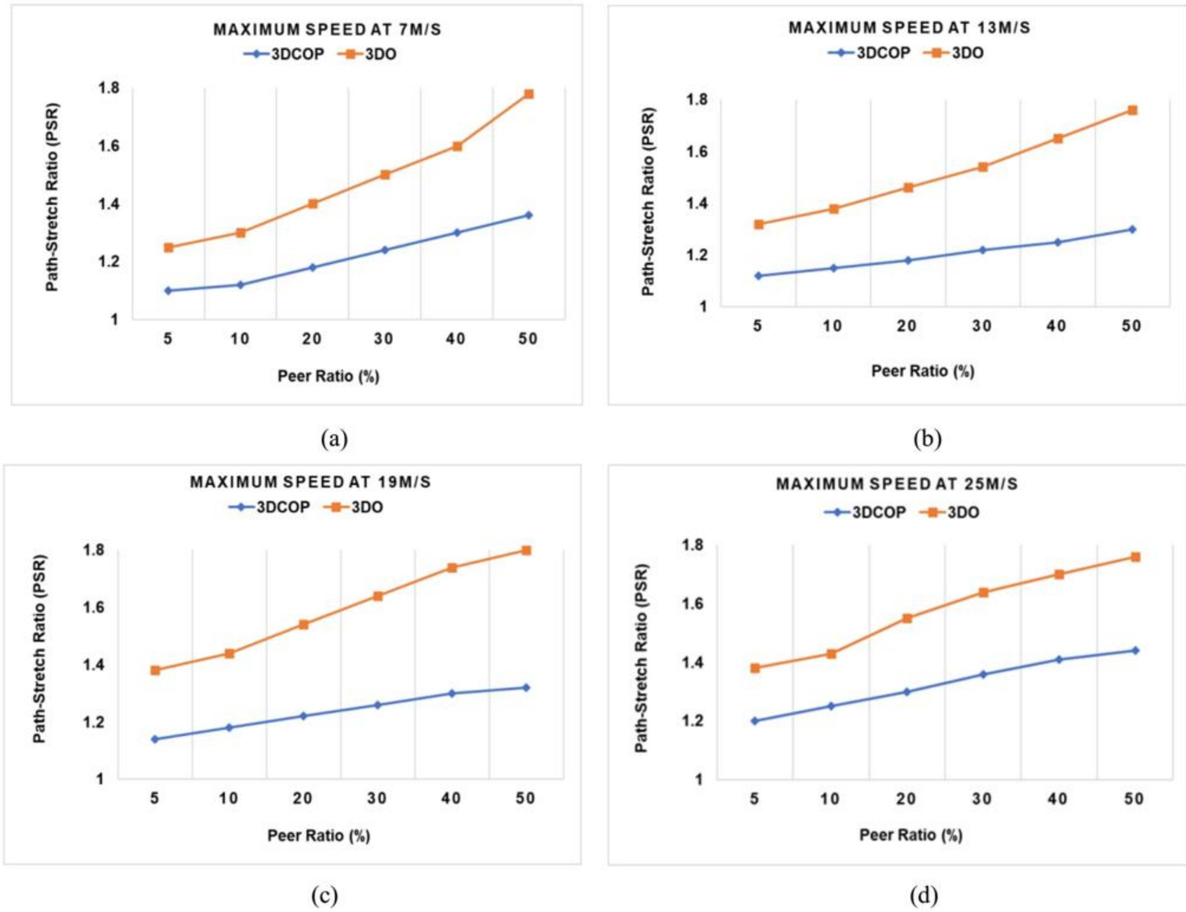

Figure 10: Path-Stretch Ratio vs. Peer Ratio at Different Node Speeds

5.4. AVERAGE FILE DISCOVERY DELAY

In this segment, the accessible routing paths' efficiency is measured by considering the delay in locating the stocked file in the network. It is computed by assessing the time needed to approach the stocked file in the physical topology. Average file discovery delay is considered one of the critical parameters in analyzing the impact of mismatch issues on 3DCOP and 3DO.

In Figure 11, the average file discovery delay is demonstrated for both 3DCOP and 3DO, considering the rise in OPP speeds and ratios. Significant routing traffic and contention are observed due to the persistent network topology and raised OPP ratio. In comparison to 3DCOP over mobile ad hoc networks, the average file discovery delay for 3DO is increased from 37% to 55%, 35% to 48%, and 38% to 51%, 40% to 49% against different OPP ratios at OPP changing speeds 7m/s, 13m/s, 19m/s, and 25m/s, respectively. In 3DO, the longer average file discovery delay is observed while comparing with 3DCOP over MANETs.

6. CONCLUSIONS AND FUTURE DIRECTIONS

The linkage of overlay participating peers at the overlay over mobile ad hoc networks is critical. In this research paper, a three-dimensional clustered peer-to-peer overlay protocol is presented to address the issues raised due to

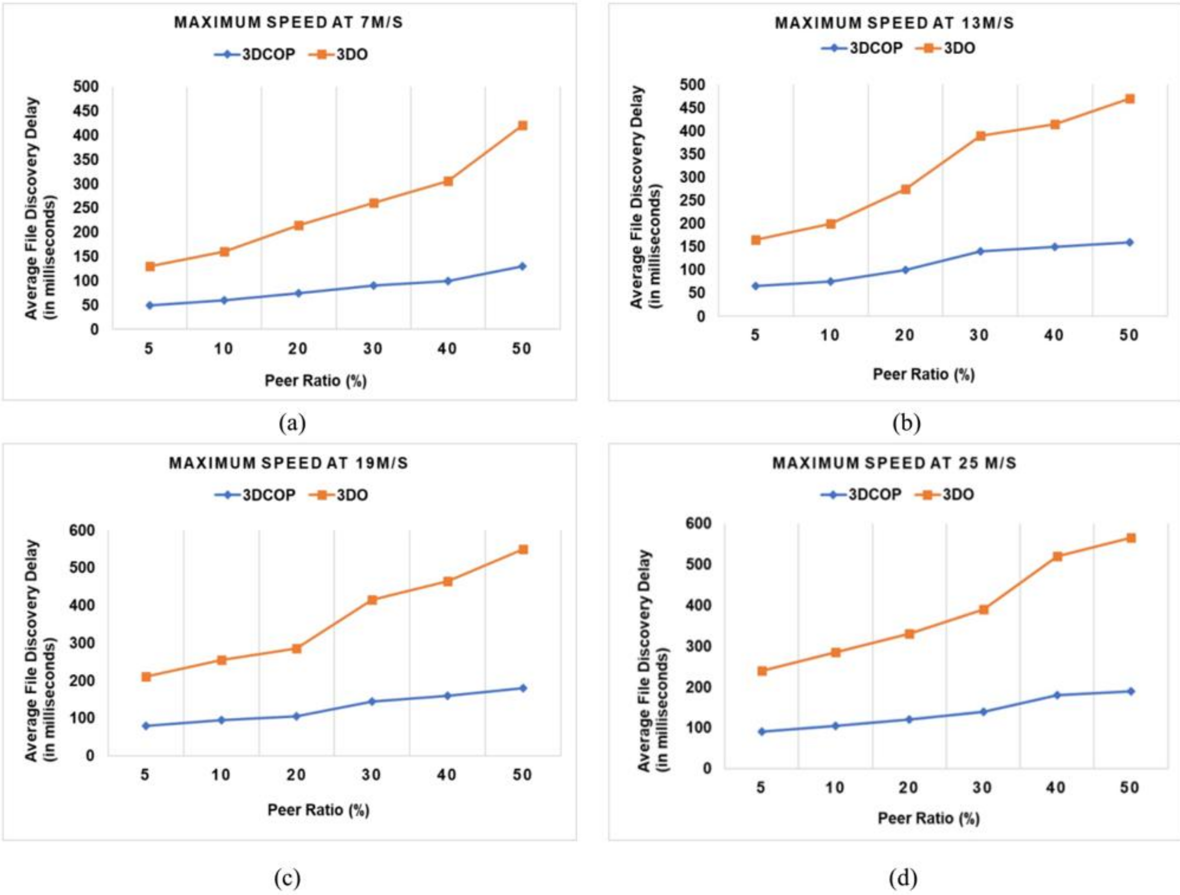

Figure 11: Average File Discovery Delay vs. Peer Ratio at Different Node Speeds

high mobility scenarios effectively. The proposed scheme introduces the idea of overlay clusters over mobile ad hoc networks. The overlay clusters are constructed by considering the highest node degree rule, and hence it minimizes the number of overlay clusters. The overlay network label of the overlay cluster leader is enumerated by considering the physical intra-neighboring relations with other adjacent neighboring overlay cluster leaders. The overlay cluster leader calculates its overlay network label and allocates the similar label to all the overlay cluster members attached to it (one-hop only) in the overlay cluster. Consequently, the proposed approach provides greater flexibility against node movement or failure scenarios over mobile ad hoc networks. It is proved through the simulation results that the proposed scheme remarkably performs better than the three-dimensional overlay protocol. Also, the proposed mechanism significantly minimizes file retrieval delays, specifically in the high mobility scenarios. In the future, we aspire to enhance our work to effectively deal with the security-related problems in peer-to-peer overlay protocols over mobile ad hoc networks. Furthermore, our emphasis will be on presenting novel remedies to the issues, e.g., network merging and partition, along with efficacious merging and partition detection mechanisms. We are interested in presenting a detailed survey of related existing peer-to-peer overlay approaches over mobile ad hoc networks.

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