A SOFTWARE-DEFINED NETWORKING-BASED LOAD-BALANCED HANDOVER CONTROL SCHEME FOR DISTRIBUTED MOBILITY MANAGEMENT IN VEHICULAR COMMUNICATION

GIẢI PHÁP CHUYỂN GIAO VÀ CÂN BẰNG TẢI DỰA TRÊN MẠNG ĐIỀU KHIỂN BẰNG PHẦN MỀM CHO QUẢN LÝ DI ĐỘNG PHÂN TÁN TRONG MẠNG XE CỘ

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Abstract - Distributed Mobility Management (DMM) for vehicular communication networks was introduced to mitigate these issues of high-mobility scenarios, but load balancing and latency problems are still encountered. This paper proposes SDN-LB-DMM, a load-balanced handover control scheme for DMM leveraging Software-Defined Networking (SDN) to address these limitations. The proposed approach integrates a unified cost matrix that combines Received Signal Strength Indicator (RSSI) and access point (AP) loading to optimize the assignment of multiple mobile nodes (MNs) to next access points (NAPs) under an SDN controller. The handover decision is formulated as a linear programming model, solved using the Simplex method and refined with the Branch and Bound technique to achieve optimal integer solutions. Simulation results demonstrate that SDN-LB-DMM improves throughput, and reduces latency and packet loss.

Key words - Distributed Mobility Management (DMM); Handover; Mobility Management; Software Defined Network (SDN); Vehicular Network

Tóm tắt – Quản lý di động phân tán (DMM) cho mạng truyền thông liên lạc xe cộ đã được giới thiệu để giảm thiểu các vấn đề trong các tình huống di động cao, nhưng vẫn còn gặp phải các vấn đề về cân bằng tải và độ trễ. Để khắc phục hạn chế này, bài báo này đề xuất SDN-LB-DMM, giải pháp chuyển giao cân bằng tải cho DMM tận dụng mạng điều khiển bằng phần mềm (SDN). Phương pháp được đề xuất tích hợp một ma trận chi phí thống nhất kết hợp. Cường độ tín hiệu nhận được (RSSI) và tải điểm truy cập (AP) được sử dụng để tối ưu hóa các nút di động (MN) cho các điểm truy cập tiếp theo (NAP) dưới bộ điều khiển SDN. Quyết định chuyển giao được xây dựng dạng mô hình lập trình tuyến tính, được giải bằng phương pháp Simplex và kỹ thuật Branch and Bound để đạt được các giải pháp số nguyên tối ưu. Kết quả mô phỏng chứng minh rằng tiếp cận SDN-LB-DMM cải thiện thông lượng, đồng thời giảm độ trễ và mất gói tin.

Từ khóa – Quản lý di động phân tán (DMM); Chuyển giao; Quản lý di động; Mạng điều khiển bằng phần mềm (SDN); Mạng xe cộ.

1. Introduction

The speedy growth of intelligent transportation systems and vehicular networks has significantly increased the demand for reliable, low-latency communication to support both safety-critical and infotainment applications [1]. In these highly dynamic environments, vehicles - acting as mobile nodes (MNs) - frequently move across multiple access points (APs) coverage areas, resulting in frequent handovers and fluctuating connection quality. Traditional Vehicle-to-Infrastructure (V2I) association methods, which rely on Received Signal Strength Indicator (RSSI), often lead to unbalanced AP loading: some APs become overloaded while others remain the lightly loaded, degrading network performance and Quality of Service (QoS) [2]. Mobile networks are expected to seamlessly integrate mobile Internet services and wireless access technologies into an all-IP network environment, ensuring continuous service delivery. A key challenge in realizing this vision is the development of intelligent mobility management protocols capable of sustaining ongoing communications and enabling seamless mobility as users traverse heterogeneous network infrastructures. A variety of IP-based wireless technologies - such as Wi-Fi, IEEE 802.11p, and WiMAX - are composed to support mobile Internet access in Vehicular Ad Hoc Networks (VANETs), where vehicles will frequently need to handover between different types of networks. Within a VANET environment, each vehicle is equipped with an On-Board Unit (OBU) that facilitates connectivity with both other vehicles and roadside infrastructure. Communication in VANETs can be broadly categorized into Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication paradigms [3]. V2I refers to the interaction between a vehicle and infrastructure-based entities, such as Road Side Units (RSUs), which facilitate real-time information exchange and service delivery to vehicles within the network.

To enhance QoS and address mobility challenges in next-generation networks, the IETF has developed several mobility management protocols, including Mobile IPv6 (MIPv6) [4] and Proxy Mobile IPv6 (PMIPv6) [5]. Both protocols follow a centralized mobility management approach, employing a central anchor entity - specifically, the Home Agent (HA) for the Mobile Node (MN) in host-based MIPv6, and the Local Mobility Anchor (LMA) in network-based PMIPv6. However, this centralized design introduces limitations such as suboptimal routing paths and insufficient dynamic mobility support, particularly when handling large volumes of mobile traffic through a centralized anchor. To address these challenges, the Internet Engineering Task Force (IETF) proposed the Distributed Mobility Management (DMM) architecture, which decentralizes mobility anchors by relocating them closer to the MN [6], [7]. This architectural shift enables improved scalability, enhanced reachability, and better handover performance, aligning with the evolving demands of future mobile networks. Numerous research efforts have been dedicated to supporting distributed operations within the DMM framework, with the goal of overcoming mobility management challenges inherent to decentralized architectures. However, despite its benefits, DMM still encounters persistent challenges, notably high handover latency and the complexity of tunnel management.

Software-Defined Networking (SDN) offers a promising solution by decoupling the control and data planes, providing a centralized, global view of the network and enabling intelligent, dynamic control over efficient traffic management and association decisions [8], [9]. In these studies, authors investigated an SDN-based offloading mechanism for vehicular communication, where m mobile nodes (MNs) are dynamically assigned to n the next access points (NAPs) under the supervision of an SDN controller. The efficient traffic management approach is deployed by a cost matrix that integrates both RSSI values and the current loading status of each AP, aiming to balance the trade-off between connection quality and load distribution. The load-balanced problem is formulated as a Linear Programming (LP) model, and an optimization method is employed to determine the optimal assignment of vehicles to APs effectively.

Several studies have explored DMM handover control schemes leveraging SDN, utilizing the SDN controller's global view to monitor vehicle mobility and thereby improve handover performance in vehicular communication networks [9], [10]. However, two critical issues remain to be addressed as follows:

1. How can efficient traffic management decisions be achieved in vehicular communication networks to improve load balancing while maintaining high connection quality?

2. How can an SDN controller optimally assign multiple mobile nodes (MNs) to multiple next access points (NAPs) by jointly considering RSSI and AP loading in a unified cost matrix, and effectively solve the problem using the Simplex method combined with the Branch and Bound approach?

Since the DMM method has turned into a gradually crucial area of research interest, we proposed a SDN approach to load-balanced handover control scheme in DMM for vehicular communication, which is called SDN-LB-DMM, to support the handover decision to improve DMM's handover performance. Thus, the proposed SDN-LB-DMM method can (1) support to optimize handover decisions in vehicular communication networks to improve load balancing through the use of SDN Controller and thus reduce delay time and improve the throughput and (2) provide a robust and scalable efficient traffic management strategy for vehicular networks enhancing both network performance and user experience in dynamic, high-mobility scenarios to reduce handover delay and loss packets.

2. Related work

This section introduces DMM control schemes and the related IP mobility protocols using SDN in vehicular networks.

2.1. Distributed Mobility Management (DMM)

The IETF has defined network-based DMM, which decentralizes the functions of the LMA in PMIPv6 by distributing them across all access routers, referred to as MAARs. DMM adopts a flatter system architecture by relocating the mobility anchor function closer to MN. There are two primary types of DMM: fully distributed and partially distributed architectures [7], [10].

In the fully distributed DMM, both the control plane and data plane are decentralized to each MAAR. These routers independently manage control signaling and data packet forwarding. However, this approach faces significant challenges due to the lack of shared knowledge among MAARs regarding each other's advertised prefixes and states. In contrast, the partially distributed DMM retains a centralized control plane via a Centralized Mobility Database (CMD), while distributing the data plane among the MAARs. In this scheme, the role of the Mobile Access Gateway (MAG) from PMIPv6 is replaced by MAARs, which are responsible for (i) detecting MN attachment, (ii) providing IP connectivity and forwarding packets to/from the Internet, (iii) acting as a local mobility anchor for attached MNs, and (iv) forwarding packets to the next MAAR when MN moves. The CMD serves as a centralized repository, maintaining the current mobility sessions and managing handovers by exchanging Proxy Binding Update (PBU) and Proxy Binding Acknowledgement (PBA) messages with MAARs.

Figure 1 illustrates the handover process in partially distributed DMM. Initially, when an MN attaches to MAAR1, it sends a Router Solicitation (RS) message. Upon receiving the RS, MAAR1 notifies CMD by sending a PBU. CMD responds with a PBA and creates a new entry for the MN, recording its current location.

When the MN moves from MAAR1 to MAAR2, it sends another RS to MAAR2. MAAR2 then notifies CMD by exchanging PBU/PBA messages. CMD updates the corresponding Binding Cache Entry (BCE) to reflect the MN's new location and sends a PBA message to MAAR2, containing information about MAAR1. Additionally, CMD sends a PBU to MAAR1, informing it of the MN's new location at MAAR2. Upon receiving the PBA, MAAR2 establishes a bi-directional tunnel with MAAR1. This tunnel enables the redirection of ongoing IP flows from MAAR1 to MAAR2, ensuring session continuity. Meanwhile, MAAR1 confirms the update to CMD with a PBA. After establishing the tunnel, MAAR2 advertises a Router Advertisement (RA) to the MN, signaling the updated connection path. This handover process repeats every time the MN changes its serving MAAR.

By reducing dependency on a centralized core and avoiding unnecessarily long routes, the DMM architecture improves scalability compared to PMIPv6. Overall, DMM offers notable advantages over centralized mobility management. However, despite these improvements, signaling overhead and handover latency remain high in partially distributed DMM, necessitating further optimization.

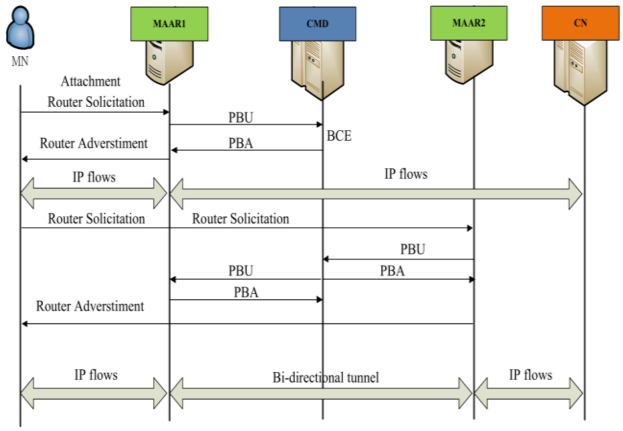

Figure 1. *The traditional partial DMM message flow chart*

2.2. Software Defined Networking (SDN) for mobility management

With its centralized control logic, the SDN's architecture provides a holistic view of the network, enabling it to address users' QoS requirements effectively. There is a growing trend toward leveraging SDN as a foundation for future mobility support solutions on the Internet. Several key advantages of SDN drive this: (1) it offers a programmable and dynamically reconfigurable network architecture, (2) it simplifies mobility management by decoupling the control plane from the underlying hardware, and (3) it enables seamless handover by allowing network operators to efficiently modify, correct, and upgrade network functions to meet evolving demands of vehicular Internet services.

Several studies have leveraged the SDN paradigm to enhance mobility management in vehicular networks. In [10], the authors presented an optimization framework for task offloading and scheduling in an SDN-integrated Mobile Edge Computing (MEC) environment, comparing Particle Swarm Optimization (PSO) and Q-learning algorithms. The study showed the improvements in task completion time and energy consumption by adapting offloading strategies. This work pointed the potential of SDN controllers to assign the resource allocation in fast-changing vehicular environments. However, a key limitation is its focus on simulation models rather than real-world vehicular mobility. Moreover, the lack of communication delays and handover effects makes it less representative of real vehicular scenarios.

The authors in [12] investigated real-time task offloading in the Internet of Vehicles (IoV) by dynamically assigning SDN controllers to manage offloading decisions. Their method balances the load across multiple SDN controllers to improve network responsiveness and reduce task processing delays. Simulation results show improvements in control plane scalability and reduced bottlenecks during high load periods. This study addresses the challenge of distributed control in large-scale vehicular networks. However, the paper lacks evaluation under fast vehicle handovers and dynamic topology changes, which are common in vehicular environments. Furthermore, the approach assumes reliable controller connectivity, which may not hold in sparse or disconnected vehicular scenarios.

The authors in [13] proposed an SDN-based offloading framework within fog computing for Machine-Type Communications (MTC), using priority-based flow management to reduce service delays. Their model animatedly redirects traffic to neighboring fog nodes to avoid bottlenecks and improve response time. The results show reduced latency and enhanced resource utilization in edge computing environments. This research is related to vehicular communications where low latency is critical for safety and control applications. However, the framework adopts relatively stable fog node availability, which may not be feasible in highly mobile vehicular networks with intermittent connectivity. Additionally, energy consumption at the vehicular end was not addressed, which could limit the for battery-powered vehicles.

In [14], this paper proposes LC-SDN-DMM, a load-considered handover control scheme that integrates SDN into DMM for vehicular networks, aiming to enhance handover performance by considering both RSSI and network load in selecting the next MAAR. The system optimizes handover decisions by leveraging SDN's centralized control and global view while maintaining distributed anchor points to mitigate centralized bottlenecks. However, the approach introduces several limitations: the selection algorithm incurs higher computational overhead due to the real-time processing of multiple metrics, and signaling traffic remains high, especially when frequent evaluations of multiple candidate APs are required under high-mobility conditions.

Different from the aforementioned method, it needs to have the proposed method which adopts a centralized management strategy, leveraging the SDN controller equipped with centralized mobility database (CMD) functionalities. By utilizing the SDN's global network view, the controller can compute the most suitable new mobility anchor router, thereby achieving significant throughput improvements and maximizing network resource utilization. Additionally, the SDN controller enables load-aware handover decisions by optimally assigning multiple mobile nodes (MNs) to multiple candidate the next access points (APs). As a result, the proposed method effectively reduces handover delay and packet loss, resulting in more reliable and efficient network management.

3. The proposed SDN-LB-DMM method

Details of the proposed SDN approach to load-balanced handover in DMM for vehicular communication (SDN-LB-DMM) is presented in this Section.

When the current point of attachment (PAP/MAAR1) experiences high loading due to a large number of Mobile Nodes (MNs) connected simultaneously, the network quality of service degrades. To mitigate this issue, shifting a subset of MNs from PAP/MAAR1 to another candidate at the next access points (NAPs/MAARs) is necessary. Figure 2 depicts the message flowchart of the proposed SDN-LB-DMM scheme. The SDN controller performs this handover decision and traffic management by selecting target APs based on a cost matrix that integrates RSSI, AP loading, and bandwidth metrics. An optimal assignment of MNs to APs is determined by solving a linear optimization problem using the Simplex method, ensuring reduced load on PAP/MAAR1 and improved overall network performance.

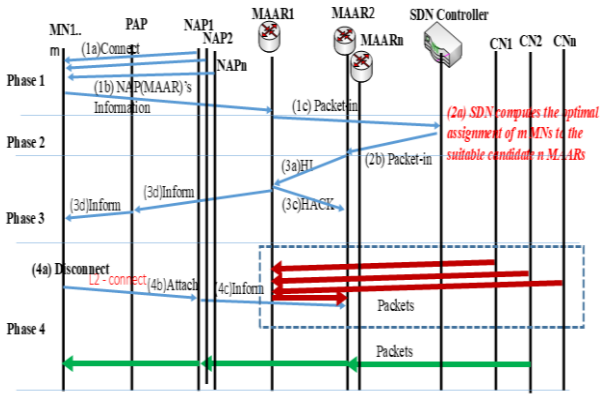

Figure 2. *The message flow chart of the proposed SDN-LB-DMM scheme*

Phase 1: (1a) As the number of connected MNs increases and utilizes high bandwidth, the load on PAP/MAAR1 increases, which may result in network congestion and degraded quality of service. This happens when the loading on PAP/MAAR1 exceeds a defined threshold, i.e., 80%. (1b) Those MNs received signal strength from neighboring access points, specifically MAAR2/NAP2 and MAAR3/NAP3. The MN sends a measurement report to MAAR1, containing the signal strength levels of MAAR2 and MAAR3, which MAAR1 then uses to identify MAAR2 and MAAR3 as candidate MAARs/NAPs for potential handover. (1c). MAAR1 compiles a binding update Packet-In message containing the candidate MAARs' information and forwards it to the SDN controller. This information includes each candidate MAAR's current load, signal strength (RSSI), and the number of connected MNs. The SDN controller Is assumed to host a CMD that maintains MN statuses and active session records.

Phase 2. (2a) The SDN controller collects the received information and computes the optimal assignment approach of each MN to one of the candidate MAARs by solving an optimization problem based on a cost matrix that integrates RSSI and AP loading, using the Simplex method. This method allows the SDN controller to select the most suitable target MAAR (e.g., MAAR2) for each MN to reduce the unbalanced loading and maintain the uninterrupted service. We proposed the SDN-LB-DMM with four steps as follows:

Step 1: Define Problem Context and Motivation

The SDN controller collects real-time network state data, including signal strength, AP load, and bandwidth availability. The primary goal is to assign each MN to a AP in a way that balances signal quality, AP loading, and bandwidth demand. This assignment problem is formulated as an optimization problem where the total connection cost is minimized under capacity and connectivity constraints. Using an optimization-based approach, the system ensures efficient resource utilization while preventing AP overloading.

Step 2: Define Cost Matrix Definition

Let *m* denote as the number of Mobile Nodes (vehicles), *n* denote as the number of the Next Access Points (NAP), $RSSI_{ij}$ denote as the RSSI from NAP j to MN i. A key element of the proposed SDN load balancing control scheme is the definition of the cost matrix C_{ij}, which quantifies the "cost" of connecting MN i to NAP j. The cost function Integrates 03 critical factors: the normalized RSSI, the normalized load at the NAP, and the requested bandwidth relative to the available bandwidth at the NAP.

$$C_{ij} = w_1\left(1 - RSSI_{ij}^{norm}\right) + w_2 \cdot Load_j^{norm} + w_3 \cdot \frac{RequestBW_i}{AvailableBW_j} \quad (1)$$

$$RSSI_{ij}^{norm} = \frac{RSSI_{ij} - RSSI_{min}}{RSSI_{max} - RSSI_{min}} \quad (2)$$

$$Load_j^{norm} = \frac{Load_j}{L_j^{max}} \quad (3)$$

Here, w_1, w_2, w_3 are weight factors that balance the influence of signal quality, AP loading, and bandwidth demand, respectively. The normalized RSSI denotes as $RSSI_{ij}^{norm}$, which is scaled the RSSI from 0 to 1 based on the minimum and maximum observed RSSI values from MN i to NAP j across the network. $Load_j^{norm}$ denotes as the normalized load representing the current AP j load relative to its maximum capacity. $RequestBW_i$ denotes the requested bandwidth by MN i; $AvailableBW_j$ denotes the available bandwidth at AP j. The term $\frac{RequestBW_i}{AvailableBW_j}$ penalizes assignments where a mobile node's bandwidth demand exceeds the AP's available capacity. Each factor in the cost function increases the cost when network conditions deteriorate or demands are high. A lower normalized RSSI, a higher AP's load, or a higher requested bandwidth all result in higher assignment costs. Therefore, the goal of the algorithm is to minimize the total cost and the suitable assignments with better signal quality, less congested APs, and feasible bandwidth allocation.

Step 3: Optimization Problem Formulation

The objective of the SDN controller is to determine the assignment x_{ij} of each MN to an NAP that minimizes the total connection cost. This objective is mathematically formulated as Equation 4. The decision variable x_{ij} indicates whether MN i is assigned to AP j. The cost matrix C_{ij} is defined as Equation 1.

$$x_{ij} = \begin{cases} 1 & \text{if MN } i \text{ is assigned to AP } j \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

$$\text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}\, x_{ij} \quad (5)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall i = 1,2,\ldots,m, \quad (5a)$$

$$\sum_{i=1}^{m} l_i \times x_{ij} \le L_j^{max} \quad \forall j = 1,2,\ldots,n \quad (5b)$$

The formulation is subject to two main constraints to ensure a valid and feasible solution. The first constraint (5a) $\sum_{j=1}^{n} x_{ij} = 1$ ensures that each MN is assigned to exactly one AP. The second constraint (5b) $\sum_{i=1}^{m} l_i\, x_{ij} \leq L_j^{max}$ ensures that the total load assigned to an AP does not exceed its maximum capacity. Here, l_i represents the load contribution of MN i, while L_j^{max} represents the maximum allowable load at AP j. The binary nature of x_{ij} enforces that a MN cannot be partially connected to multiple APs, which reflects real-world constraints. This problem falls under the category of binary ILP due to its linear objective function and linear constraints. Solving this optimization ensures balanced assignments while respecting both connectivity and capacity limitations.

Step 4: Solving with Simplex and Branch and Bound

The Simplex method, an existing linear programming algorithm, is used to solve problem (5) [15]. The Simplex method minimizes total cost. It iteratively moves along the edges of the feasible region of the LP problem to find the optimal corner point minimizing total cost. If we relax x_{ij} to continuous variables $0 \leq x_{ij} \leq 1$, this problem can be formulated as a Linear Programming (LP) problem, which is solvable using the Simplex method. However, the Simplex solution may yield fractional values for x_{ij}, which are not valid for our binary assignment problem. The Branch and Bound (BnB) method is applied after the Simplex phase to obtain an integer solution. The solution space of BnB method is recursively divided into subproblems by fixing one fractional variable at a time to 0 or 1, creating two new branches. Each subproblem is solved again using Simplex to determine its feasibility and objective value. Subproblems that violate constraints or have worse objective values than the best known integer solution are pruned, reducing the search space.

To clarify the solution approach, we provide the example demonstrating how to assign 5 MNs to 3 APs with the objective of assigning each MN to one AP while minimizing the total cost. The cost matrix specifies the communication cost between each MN and AP, such as $C = \begin{bmatrix} 4 & 2 & 3 \\ 3 & 5 & 2 \\ 4 & 1 & 3 \\ 2 & 4 & 3 \\ 3 & 2 & 4 \end{bmatrix}$. The objective function sums these costs weighted by binary decision variables x_{ij}, where $x_{ij} = 1$ if MN i is assigned to AP j. Constraints ensure that each MN connects to exactly one AP, with all x_{ij} being either 0 or 1. This formulation leads to a 0-1 Integer Linear Programming (ILP) problem that cannot be directly solved by standard linear programming.

To solve this problem, we first relax the integer constraints and solve it as a standard Linear Programming (LP) problem, allowing $0 \leq x_{ij} \leq 1$. Suppose the LP solution yields a fractional value, such as $x_{23} = 0.5$, indicating that MN2 is split between NAP2 and NAP3. The BnB method enforces integer solutions since fractional assignments are not feasible in practice. BnB begins by generating two subproblems: one with $x_{23} = 0$ fixed, and the other with $x_{23} = 1$ fixed. Each subproblem is subsequently solved as an individual LP problem, incorporating the additional constraint imposed by the respective branch. Each subproblem is then evaluated to verify feasibility and check whether all variables satisfy the integer constraints. If a subproblem yields an integer solution, it is recorded as a candidate solution, and its total cost is saved. If the solution remains fractional, the algorithm continues branching by selecting another fractional variable and creating new subproblems for further exploration. If a subproblem is found to be infeasible or its objective value is worse than that of an existing candidate solution, the branch is pruned to reduce computational effort. This recursive process continues, progressively solving the better LPs with additional fixed variables in each branch, until an optimal integer solution is found.

The algorithm continues until all branches are either pruned or yield feasible integer solutions. Finally, the algorithm compares all candidate solutions and selects the one with the lowest total cost Z as the optimal assignment. In this example, an optimal solution may assign MN1 to AP2, MN2 to AP3, MN3 to AP2, MN4 to AP1, and MN5 to AP2 with a total cost of 9. This approach ensures that the traffic management decision balances both signal quality and AP loading under integer constraints. By applying the BnB method, we systematically explore all possible assignments without enumerating every combination. The method guarantees finding the optimal integer solution for the vehicular communication traffic management problem. Therefore, the SDN controller runs the Simplex algorithm and BnB method to solve the linear programming problem and determine the optimal assignment of MNs to NAPs.

Phase 3: (3a) Afterward, the SDN controller notifies the selected mobility anchor for the handover MNs, i.e., MAAR2, by sending a Packet-In message. (3b) Subsequently, MAAR2 sends a binding Handover Initiate (HI) message to MAAR1. In response, MAAR1 replies with a binding Handover Acknowledge (Hack) message to MAAR2, establishing a bidirectional tunnel between MAAR1 and MAAR2.

Phase 4: When the load at PAP/MAAR1 falls below a predefined threshold, the SDN controller determines the optimal assignment of MNs to next network access points (NAPs), selecting handover targets from NAP2...k/MAAR2...k. Once a target NAP/MAAR is selected for the MN's connection, the MN initiates disconnection from the domain of PAP1/MAAR1 and begins transitioning toward the next NAP/MAAR (e.g., MAAR2). The MN then sends a Layer 2 (L2) report to NAP2 and attaches to MAAR2's domain. The SDN controller updates the packet forwarding rules in the data plane to ensure the MN continues receiving packets from Correspondent Node 1 (CN1) without disruption. Upon successful attachment to MAAR2's domain, ongoing packets from CN1 are redirected to MAAR2 and forwarded to the MN via an optimized route from CN1 to MAAR2. Meanwhile, a new connection from CN2 to the MN is established directly, eliminating the need for tunneling.

Finally, the handover processing of those MNs from MAAR1 to MAAR2..k is finished.

4. Performance analysis

This Section describes the implementation setup and the comparative analysis metrics used to evaluate the proposed SDN-LB-DMM scheme against the conventional DMM approach. Both mobility management methods were implemented using the ns-3 network simulator **Error! Reference source not found.**, a discrete-event simulator developed in C++. The ns-3 framework comprehensively supports IEEE 802.11 network environments through its built-in modules. Vehicle mobility patterns were generated using SUMO (Simulation of Urban Mobility) [17], an open-source traffic simulation tool.

Table 1. *Simulation parameters*

Paramaters	Value
Network size	1000mx2000m
Data packet size	55 bytes
simulationTime	60s
TxPowerStart	10.0
Application layer datarate	100Mbps
Number of vehicles	10
Radio transmission range	400m
PropagationDelay	ProbabilisticV2vUrbanChannel Condition
No. of hop count	1-10

Table 1 summarizes the key network parameters configured for the simulations. In the simulation scenario, MNs were randomly distributed around multiple APs. The SDN controller maintained a global view of the network, enabling it to monitor real-time network status and make dynamic routing and handover decisions. In the simulation environment, the network comprised 20 vehicles moving at 3 m/s within an IEEE 802.11n infrastructure. The architecture included 5 MAARs managing 6 APs and connected to 6 Correspondent Nodes (CNs). For each experiment, the simulation was executed 40 times to obtain averaged performance results. The evaluation compared the proposed SDN-LB-DMM method and the conventional DMM method across three key performance metrics: handover delay, throughput, and packet loss ratio.

Figure 3 shows the relationship between average transmission latency (y-axis) and the number of vehicles (x-axis) for two mobility management approaches: the proposed SDN-LB-DMM and the conventional DMM. As the number of vehicles increases from 1 to 10, both approaches experience an increase in average transmission latency, indicating that higher network load leads to higher communication delays. However, the proposed SDN-LB-DMM consistently maintains a lower latency than the conventional DMM at every vehicle count. The gap between the two curves widens as the number of vehicles grows, which clearly shows that the proposed method scales better under increasing load. For example, at 10 vehicles, the latency difference between the two approaches is more pronounced than at 1 or 2 vehicles. This improvement is due to the SDN controller’s intelligent, load-aware decision-making, which dynamically selects the next MAAR based on real-time network conditions. By proactively assigning MNs to less congested MAARs, the SDN-LB-DMM reduces network bottlenecks, leading to shorter handover delays and faster resumption of data transmission after handover. Therefore, the results demonstrates that the proposed SDN-LB-DMM offers superior handover performance and scalability, achieving lower average transmission latency than the conventional DMM, especially as the number of vehicles increases.

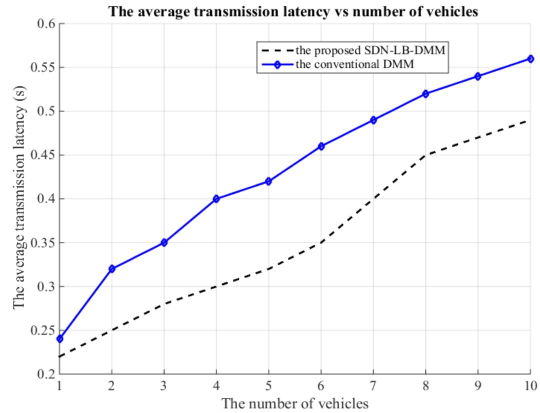

Figure 3. *Average transmission latency vs. number of vehicles.*

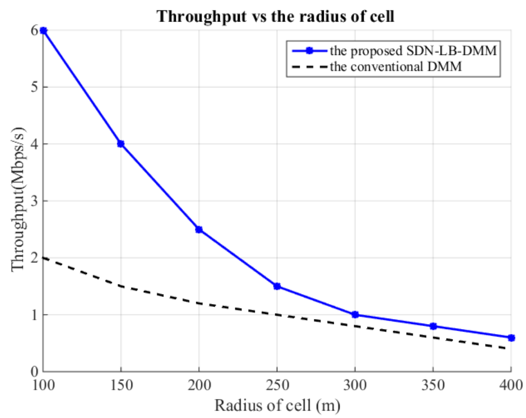

Figure 4. *Throughput vs. the radius of cell*

Figure 4 shows the average throughput of the proposed SDN-LB-DMM scheme compared to the conventional DMM approach in terms of cell radius. The results show that the proposed SDN-LB-DMM consistently achieves higher throughput than the conventional DMM across all cell radius. Specifically, as the cell radius increases from 100 meters to 400 meters, the throughput of both methods declines; however, the throughput of SDN-LB-DMM remains significantly higher than that of the conventional DMM. The performance gap becomes more evident as the radius increases, demonstrating the robustness of the proposed scheme in larger coverage areas. This improvement in throughput can be attributed to two key factors: (i) the handover delay in the SDN-LB-DMM scheme is shorter than that of the conventional DMM, enabling faster reconnection and data delivery; and (ii) the bidirectional tunnel is established in advance, allowing data forwarding to commence immediately once the MN completes its handover to the next MAAR. These mechanisms enable the proposed SDN-LB-DMM to maintain higher throughput even as cell sizes increase.

Figure 5 illustrates the packet loss of the proposed

SDN-LB-DMM scheme compared to the conventional DMM approach under different mobile node (MN) velocities. As the velocity of the MN increases from 1 m/s to 30 m/s, the proposed SDN-LB-DMM consistently achieves lower packet loss than the conventional DMM across all speed levels. Notably, when the MN's velocity increases from 6 m/s to 15 m/s, the packet loss in the SDN-LB-DMM remains significantly lower than that of the conventional DMM. Furthermore, as the velocity surpasses 10 m/s, the gap in packet loss between the two approaches expands, indicating that the performance advantage of SDN-LB-DMM becomes more noticeable at higher mobility speeds. This decrease in packet loss is qualified to the SDN controller's ability to proactively make handover decisions and establish necessary forwarding paths in advance, thereby reducing handover latency compared to the conventional DMM approach. Overall, the results confirm that the proposed SDN-LB-DMM scheme enhances handover performance by minimizing packet loss, especially in high-speed vehicular scenarios.

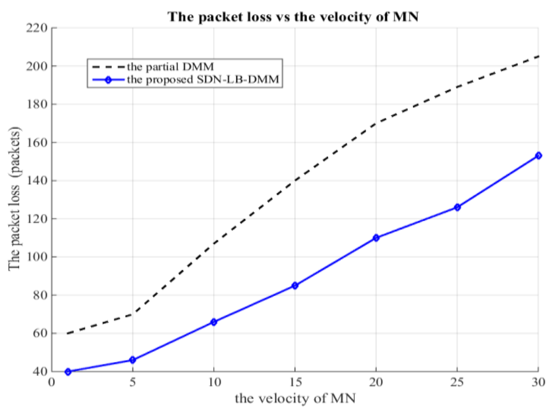

Figure 5. *The packet loss vs. the velocity of MN*

5. Conclusions

In this paper, a SDN - based approach for load-balanced handover in DMM for vehicular communication is proposed to enhance handover performance in dynamic, high-mobility environments. By integrating a unified cost matrix that considers both RSSI and AP's loading, the proposed scheme enables the SDN controller to make optimized, load-aware handover decisions for mobile nodes (MNs). The traffic management problem was formulated as a linear programming model and efficiently solved using the Simplex method with refinement through the Branch and Bound approach to ensure integer-constraint satisfaction. Simulation results confirmed that SDN-LB-DMM significantly improves handover performance compared to conventional DMM-based approaches, achieving lower handover latency, reduced packet loss, and higher throughput while maintaining better load balancing across APs. These improvements demonstrate the effectiveness of SDN-LB-DMM in addressing the scalability and performance challenges of mobility management in dynamic, high-mobility vehicular environments. Future work will explore the integration of Mobile Edge Computing (MEC) with SDN-LB-DMM to enhance further real-time responsiveness and localized service delivery in vehicular networks.

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