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Comparison between MDDV and VADD routing protocols in VANET (Case Study)

Ahmed Ghassan Hameed[1] and Mahmoud Shuker Mahmoud[2]

[1]Computer Sciences Department of Informatics Institute for postgraduate studies, Baghdad, Iraq

[1]Al-Khawarizmi College of Engineering, University of Baghdad, Iraq

[2]Al-Mansour University College, Baghdad, Iraq

en.ahmedghassan@gmail.com

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Abstract

Routing is the process of delivering a packet from a source to a destination in the network using a routing algorithm that tries to create an efficient path. The path should be created with minimum overhead and bandwidth consumption. In the literature, routing protocols in VANET were categorized in many ways, according to different aspects. In the present study, we prefer the classification based on the number of hops to reach the destination node. The literature, these are single-hop and multi-hops protocols. We first discuss the two types and then compare the MDDV (multi-hops protocol) with VADD (single-hop protocol). The comparison is theoretically and experimentally implemented by providing a network environment consisting of SUMO, VIENS and INET++ libraries within OMNeT++ simulator. The code for each protocol is written in C++ language and integrated in the OMNeT++ simulator. Several evaluation measures are used including: throughput, end-to-end packet delay, packet delivery ratio, and good put. Results reveal that none of these two protocols is ideal for all possible scenarios of VANET traffic. VADD protocol performs better for high vehicle density (with an improvement of about 15% over MDDV) and high transmission rates, whereas MDDV protocol gives better performance for low density (with enhancement of about 10% over VADD) and low transmission rates.

Keywords: Routing Protocols, VADD, MDDV, Single-hop, Multi-hop.

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مقارنة بين بروتوكلات التوجيه MDDV و VADD في بيئة VANET (دراسة تجريبية)

أحمد غسان حميد[1] و محمود شكر محمود[2]

[1] معهد المعلوماتية للدراسات العليا
[1] كلية هندسة الخوارزمي - جامعة بغداد
[2] كلية المنصور الجامعة

الخلاصة

التوجيه هو عملية تسليم حزمة من المصدر إلى المستلم في الشبكة باستخدام خوارزمية توجيه تحاول إنشاء مسار فعال. يجب إنشاء المسار بأقل استهلاك للحمل وعرض النطاق الترددي. في الأدبيات ، تم تصنيف بروتوكولات التوجيه في VANET بعدة طرق ، وفقًا لمتغيرات مختلفة. في الدراسة الحالية ، نحن فضلنا التصنيف المبني على عدد القفزات للوصول إلى العجلة المستلمة. في الأدبيات ، هذا التصنيف يشمل بروتوكولات ذات القفزة واحدة وبروتوكولات متعددة القفزات. ناقشنا النوعين أولاً ثم قارنا MDDV (بروتوكول القفزات المتعددة) مع VADD (بروتوكول القفزة الواحدة). تم تنفيذ المقارنة نظريًا وتجريبيًا من خلال توفير بيئة شبكة تتكون من مكتبات SUMO و VIENS و INET++ داخل تطبيق المحاكاة OMNeT++. تمت كتابة خطوات كل بروتوكول بلغة C++ ودمجها في تطبيق المحاكاة. تم استخدام العديد من متغيرات التقييم بما في ذلك: الإنتاجية ، وتأخير الحزمة من مركبة إلى مركبة ، ونسبة تسليم الحزم ، والمحتوى المفيد. كشفت النتائج أن أيا من هذين البروتوكولين لا يعتبر مثاليًا لجميع السيناريوهات المحتملة لحركة المرور VANET. ويمكن الاستنتاج بأن بروتوكول VADD يعمل بشكل أفضل في بيئة ذات كثافة عالية بالمركبات (مع تحسن بنسبة 15٪ تقريبًا عن MDDV) ومعدلات نقل عالية ، بينما يوفر بروتوكول MDDV أداءً أفضل للكثافة المنخفضة للمركبات (مع تعزيز حوالي 10٪ فوق VADD) ومعدلات نقل منخفضة.

الكلمات المفتاحية: بروتوكوت التوجيه، VADD، MDDV، قفزة - واحدة، قفزات – متعددة.

Introduction

Routing is the process of delivering a packet from a source to a destination in the network using a routing algorithm that tries to create an efficient path. The path should be created with minimum overhead and bandwidth consumption. In the literature, routing protocols in VANET were categorized in many ways, according to different aspects. Several researchers preferred the classification based on protocols characteristics and techniques [1-2]. In this classification, routing protocols can be grouped into five categories: topology-based, position-based, cluster-based, multicast-based, and broadcast routing protocols. Another classification is based on either single-hop or multi-hop routing [3-4]. We did a simple on-line questionnaire for 220 graduate students to select the understandable classification form 5 groups. The analysis reveals that 63% prefer the single/multi-hops classification.

The purpose of the present study is to compare two of the existing Vehicle-To-Vehicle (V2V) position routing protocols namely: Vehicle-Assisted Data Delivery (VADD) and Mobility-Centric Data Dissemination Algorithm for Vehicular Networks (MDDV).

The comparison is conducted using several scenarios with different node densities (8, 16 and 24 nodes). Four assessment parameters are adopted to evaluate the two protocols, which are throughput, end-to-end packet delay, packet delivery ratio, and goodput. The detailed calculations show that MDDV yields an enhancement of about 10% over VADD for low node density (8 vehicles), whereas VADD gives superior results with an improvement of about 15% over MDDV for high node density (24 vehicles). For 16 nodes, the two protocols show approximately the same results.

Before discussing these two protocols, it is preferable to look on the types of messages and the division of protocols based on the number of hops to travel the message from the source to the destination.

Types of Messages in VANET

In general, messages in VANET are broadcast. Two types of messages are identified in VANET. The Beacon messages are broadcast between vehicles periodically (at most each 300 ms). Literature refers to these message as self-status messages, locally broadcasting status information messages, hello messages, or non-safety messages. They contain vehicle identifiers, current position, speed, and direction. The beaconing process provides a vehicle's awareness of its surroundings. Usually, vehicles need beacons from the neighbors ahead and not from the neighbors behind [5]. The other messages, called safety messages or alert messages, which are generated when nodes detect an event such as traffic congestion or accident [6]. In VANET, safety messages have priority compared to beacon messages. Besides, neighbors do not forward Beacons [7].

Single-hop versus Multi-hop Protocols

Based on the ways of spreading information in VANET, protocols can be divided into two groups: single-hop and multi-hop broadcasting. Both types of communication (single-hop and multi-hop) are suitable for safety and non-safety messages. In multi-hop broadcasting schemes, messages are sent using a flooding method. A source vehicle broadcasts the message to its neighbor's nodes, and the receiving nodes will just rebroadcast it. This process continues until the message reaches the destination vehicle. On the other hand, in single-hop broadcasting, instead of flooding packets, the source broadcasts packets using the maximum transmission rate. Each vehicle keeps information messages and updates, and only the selected node is rebroadcasting in the next broadcast cycle [8][9][10].

Fig.1 presents single and multi-hop communications [6]. As shown in single-hop, the vehicle broadcasts packets using transmission rate management (starting from the highest rate, usually 300 m distance) to reach the destination by a single-hop. The identification of the targeted destination is based on the information obtained from the beacons. The targeted destination acknowledged the source node with the receiving of the information. In multi-hop communication, the source node tries to use a short transmission rate (to reduce power consumption) for broadcasting the message to its neighbors (in the range of transmission rate). The receiving nodes (called Relays) confirm the receipt of a message and repeat the same behavior by broadcasting the packets (without modification) to their neighbors.

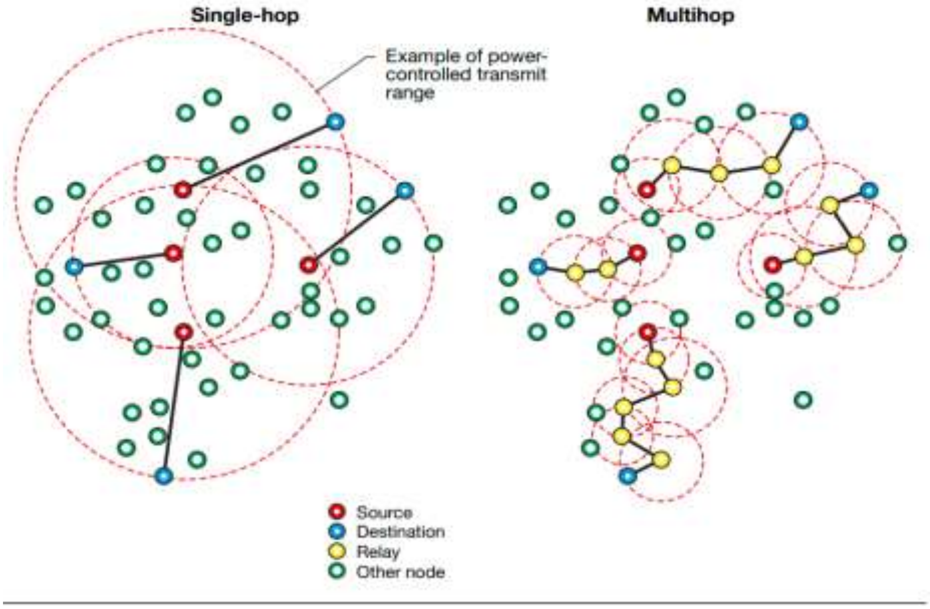


Figure 1: Single-hop vs. multi-hop communication [6]

In VANET with single-hop routing, if the destination is out of coverage area by the highest transmission rate, the source node (after getting the responses from the receiving nodes) selects a node based on, for example, the density, speed, position, and lowest delay (based on the design of the routing protocol) to carry and forward the packets. The carrier node confirms the receipt, modifies and stores the received information, and behaves as a source node. In other words, the first sender node will not track the movement of the message.

In multi-hop routing, the source node (S) will track the transmission of the message because the first Relay (R1) confirms the receipt of the message, stores and carries it, and broadcasts the packets without modification. When R1 finds another Relay (R2), it acknowledges S that the message reaches the R2, so the source S can track the movement of the message and knows the number of hops [11][12]. Only those nodes that receive the broadcast packets can become the next hop relays. When one of these relays forwards the packet, all other included nodes stop their waiting process upon hearing the rebroadcast.

Literature has shown that single-hop requires a high node density and a high transmission rate. However, its security is controlled because the source and destination nodes must guarantee mutual authentication, data confidentiality, and integrity checks. On the other hand, multi-hop routing can work in low-density node networks. Besides, it uses less power transmission, but additional security issues arise centered on data; that is, reliability and trustworthiness of data are required.The advantages of multi-hop communication in VANET are reflected in two aspects. One is for V2I communication, and the other is for V2V communication. For the layout of RSU, if only single-hop communication is allowed, its layout density is required to be high. The two RSUs must be seamlessly connected to ensure that the communication range of RSUs covers all vehicles. However, if multi-hop communication is allowed, the layout density of the RSU can be relatively reduced.

For example, in multi-hop communication, the V_A in Fig.2 is not within the communication range of RSU1; however, this communication can be achieved through V_E. On the other hand, for V2V communication, if the destination node is not within the communication range of the source node, one-hop communication cannot be completed, but multi-hop communication is possible. The maximum routing hop count parameter setting is a great significance in multi-hop VANET. A high value typically increases the chance of connection between vehicles; nevertheless, it also increases the network's routing overhead and packet collision probability.

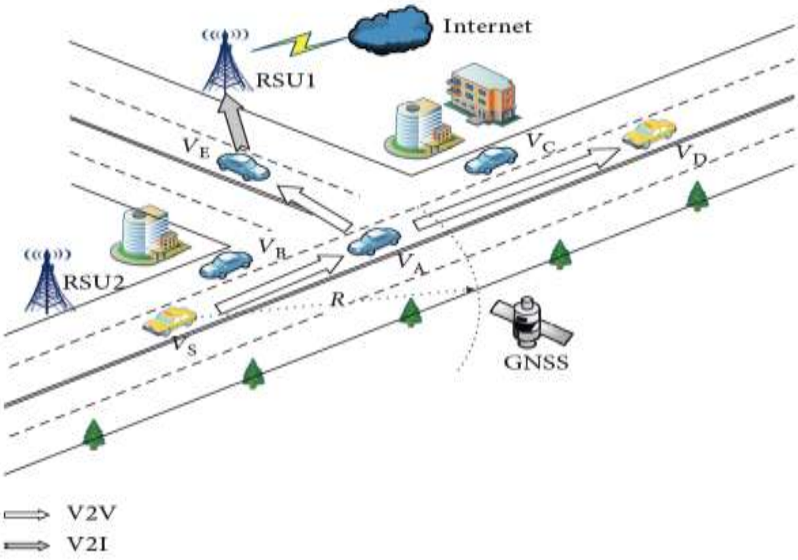


Figure 2: Demonstration of multi-hop communication [6]

For example, in Fig.2, the source node V_S needs to send a message to the destination V_D. If the maximum routing hop count parameter is = 1, the message cannot reach to V_D because the distance x between the two nodes is higher than the vehicle communication range R. When the maximum routing hop count parameter increases to 2, a possible communication path $V_S \longrightarrow V_A \longrightarrow V_D$ can be used.

When it is set to 3, four possible communication links can be established, one of which is 2-hop communication: $V_S \longrightarrow V_A \longrightarrow V_D$, and the other 3 possible communication links are 3-hop communication: $V_S \longrightarrow V_A \longrightarrow V_C \longrightarrow V_D$, $V_S \longrightarrow V_B \longrightarrow V_A \longrightarrow V_D$, and $V_S \longrightarrow V_B \longrightarrow V_C \longrightarrow V_D$. It can be seen intuitively that the appropriate value of the maximum routing hop count can increase the possibility of establishing a communication link. Nevertheless, this also increases the possibility of data packet collisions because large routing hops mean more data packets will be transmitted in the network. Therefore, we can increase the connection probability of the communication link by setting an appropriate maximum route hop value based on not increasing network conflicts as much as possible; that is, find the balance between the connection probability and the collision probability.A demonstration of single-hop is shown in Fig.3, which depends on the carry and forward theory. Node A tries to send a message to node F. Based on Beacon information, node A broadcasts packet within its local view and selects the furthest Relay (again based on the protocol used). In Fig.3, Node A selects Node B, which receives the message, acknowledges node A, behaves as a source node, and tries to establish a connection with its neighbors located in its local view. In our case, it chooses node C. Node C performs the same procedure until the message reaches node F. In this example, the first source node A does not track the path of forwarding the message; it just receives an acknowledgment from the first carrier.

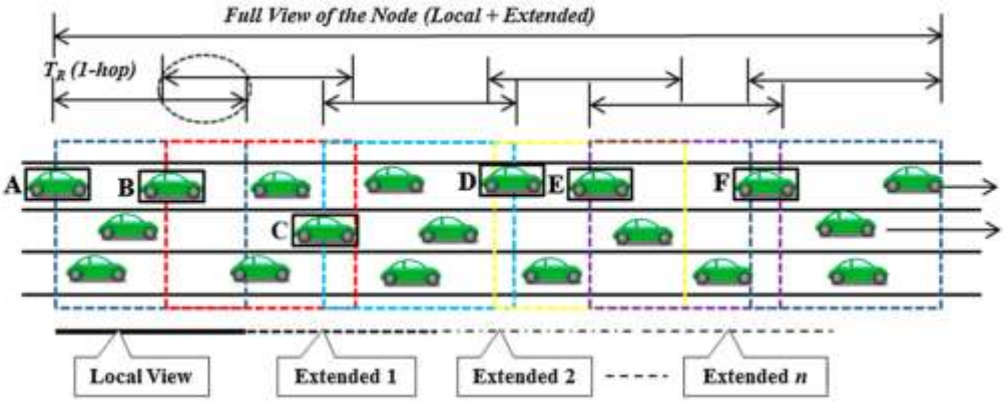


Figure 3: Demonstration of single-hop communication [5]

It is worth mentioning that for single-hop, the first source needs to know the number of hops to reach the destination, since each node can pass one hop. Therefore, the end-to-end delay criteria cannot be applied to a single-hop scheme. In single-hop routing, the metrics adopted are speed, density, position, and delay. The end-to-end delay is the sum of the times from source to destination. This term will be described in detail later.

Vehicle-Assisted Data Delivery (VADD)

VADD is a routing protocol belonging to the position category. This protocol aims to improve routing using the carry and forward technique [3] based on predictable vehicle mobility. At each intersection, the vehicle will decide and select the next forwarding path with the minimum delay. This delay depends on the road distance, average speed, and density of nodes. To solve the problem of low connectivity between nodes, a vehicle in motion carries the package when routes do not exist until it reaches a new vehicle, moves in its neighborhood, and transmits the package. However, this relay strategy can only succeed when no neighbor vehicle carrier exists. Thus, this protocol does not function with a low density of nodes [13].

1. Assumptions

- The vehicles can communicate with each other through a short-range wireless channel (100–250 m).

- The information included in the packet delivery (source ID, source location, packet generation time, destination location, expiration time) is specified by the sender and is placed in the packet header.
- A vehicle knows its location via GPS and its neighbors' location by beacon message.
- Vehicles are equipped with preloaded digital maps, which provide street-level maps and traffic statistics such as traffic density, and vehicle speed on roads at different times of the day.
- The communication adopted is single-hop.

The VADD protocol adopted the idea of a carry and forward approach to select a forwarding path with the smallest packet-delivery delay to enhance VANET network performance; the VADD protocol follows several basic principles as listed below:

- Transmit through wireless channels as much as possible.
- If the packet has to be carried through certain roads, the higher-density road should be chosen.
- Due to the unpredictable nature of VANETs, the packet is not expected to be successfully routed along the pre-computed optimal path, so dynamic path selection should continuously be executed throughout the packet forwarding process.
- The inter-vehicle distances follow an exponential distribution, with a mean distance equal to 1/density of vehicles.

Referring to Fig.4, the notations listed below are needed to specify the packet-delivery delay adjacent intersections:

r_{mn}: the road from I_m to I_n
l_{mn}: the Euclidean distance of r_{mn}
ρ_{mn}: the vehicle density on r_{mn}
v_{mn}: the average vehicle velocity on r_{mn}
d_{mn}: the expected packet-forwarding delay from I_m to I_n (between two adjacent intersections)

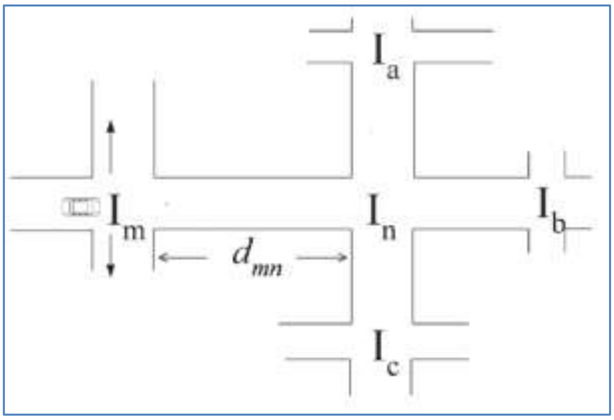


Figure 4: VADD delay model.

Giving the mean inter-vehicle distance equal to $1/\rho_{mn}$, the d_{mn} can be calculated by:

$$d_{mn} = (1 - e^{-R\,\rho_{mn}})\frac{l_{mn}\,c}{R} + e^{-R\rho_{mn}}\,\frac{l_{mn}}{v_{mn}} \qquad (1)$$

Where **R** is the wireless transmission range, and **c** is the average one-hop packet transmission delay. As indicated, Eq. (1) reveals that the inter-vehicle distance is smaller than **R** by $(1 - e^{-R\,\rho_{mn}})$ of the road, where wireless transmission is used to forward the packet. On the rest of the road, vehicles are used to carry the data.

Sometimes, the packet carrier decides to forward the packet through the non-adjacent intersection. Fig.5 indicated that the time required traveling the packet from l_a to l_b through intersections l_c and l_d is faster than directly from l_a to l_b.

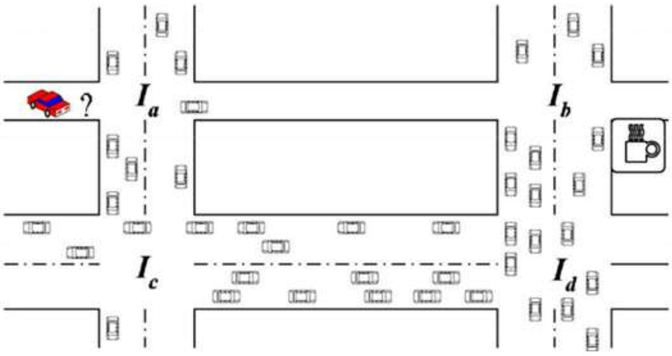


Figure 5: Example of choosing the optimum path to the destination.

The authors generalized Eq. (2) to be used whether the carrier chooses an adjacent or non-adjacent intersection. Based on Fig.4, the general form for predicting packet delivery delay is:

$$D_{mn} = d_{mn} + \sum_{N_{(j)}} (P_{jn} \, D_{jn}) \qquad (2)$$

Where D_{mn} is the expected packet delivery delay from l_m to l_n, when the carrier at I_m chooses to deliver the packet through non-adjacent intersection. P_{jn} is the probability that the packet passes through road r_{jn} at I_n. $N_{(j)}$ is the set of neighboring intersections of I_n. Due to the unlimited unknown intersections in VANET, the authors suggested using a boundary as a circle with a radius equal to the distance between the source and destination plus 1000 m. Eq(2) can be applied only to the roads within the bounded area to predict the minimum expected delay. In addition to data delivery delay, two other performance metrics are considered: data delivery ratio and data traffic overhead. Fig.6 presents the pseudo code of VADD protocol.

The pseudo code of the VADD routing protocol in VANET

```
Begin: (inputs are In, P, E); (output is to find next vehicle and forward P to it)

 In: the current intersection
 p: the packet to forward
 E[]: a list of all outgoing roads at In, sorted by the order of priority to forward p
 Nn: the number of outgoing roads at In
 Vnext: next hop vehicle for p
 P I: the priority of road r to forward packet p
 Inext(rnj): the neighbor intersection Ij (connected to In by rnj)
Enter Intersection:
    dsent ⇐ moving direction of the current packet carrier
    Periodic Probing:
    I = 0
      while I < Nn and P (E[i]) ≥ P (dsent) do
              S ⇐ all neighbors moving towards road E[i]
              Vnext ⇐ the closest node to Inext(E[i]) in S
```

```
            I + +
            if Vnext is found then
                break
            end if
        end while
        if Vnext is found then
            send a copy of the packet p to Vnext
                if P (E[i]) is the highest priority at In then
                    delete the packet from the buffer
                else
                    mark the packet as SENT
                    dsent ⇐ E[i]
                continue to hold the packet
            end if
        else
            continue to hold the packet
        end if
        Repeat Periodic Probing at the next probing interval
      Leave Intersection:
    purge all packets which have been marked SENT
```

Figure 6: Pseudo-code of VADD protocol.

Fig.7 illustrates the forwarding strategy of the VADD protocol. VADD used the beacon msg to define the location of neighbors with road information. It chooses a forwarding path with the lowest packet delivery delay. It provides the forwarding strategy by using intersection as a chance to change and optimize the direction and path of forwarding msgs.

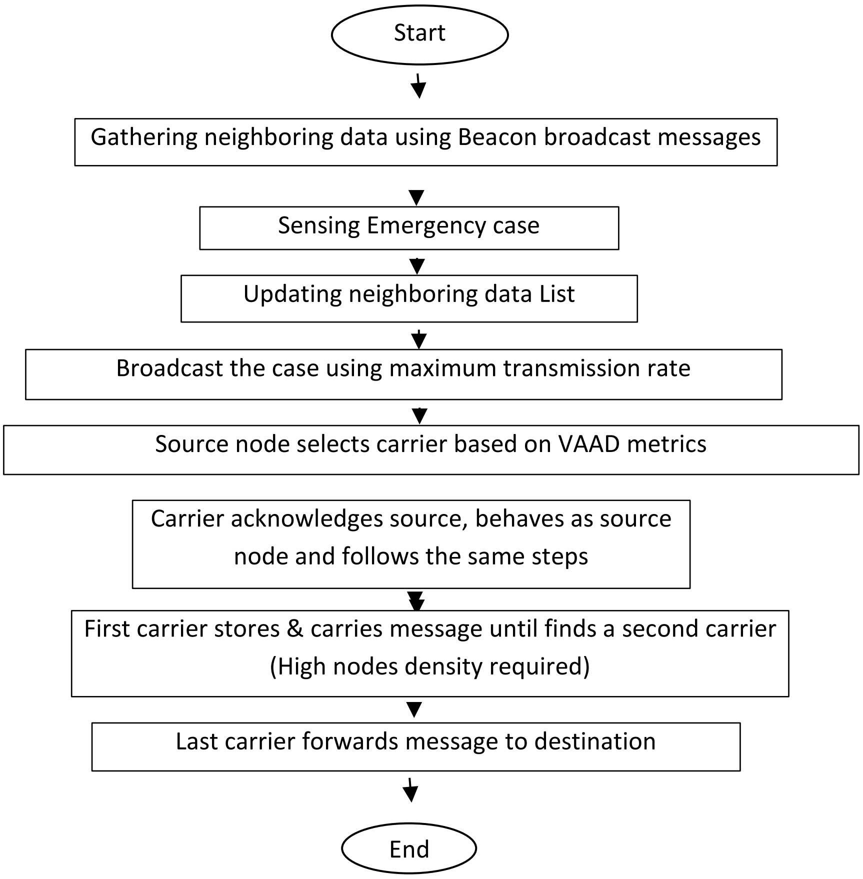


Figure 7: The forwarding strategy of the VADD protocol.

In short, VADD is a single-hop protocol that uses a high transmission rate to broadcast messages to build a routing table. The criteria for selecting nodes are density, speed, how it is closest to the destination, and delay. The distance between the source and destination nodes plays an important variable; the source node selects the furthest node as the next hop (closest to the destination). The mission of the first node is completed as it finds an acknowledgment from another node to complete the mission. The numbers of hops and end-to-end delay are not important aspects in VADD.

Mobility-Centric Data Dissemination Algorithm for Vehicular Networks (MDDV)

The MDDV protocol is designed to exploit vehicle mobility to disseminate data from source to destination [2]. It combines the idea of opportunistic forwarding, transfers according to the trajectory, and geographical forwarding. Data dissemination concerns information transport to intended receivers while meeting particular design objectives. The design objectives include low delay, high reliability, low memory occupancy, and low message-passing overhead. The intended receivers are those specifying interest in the information. Users may define arbitrary interests: “all vehicles going to the football stadium", " police cars that are close by" , etc. The authors are only concerned with those interests that data dissemination algorithms can readily exploit (that is time and location).

Four dissemination services with an immediate application are unicast, multicast, anycast, and scan. Unicast with precise location means a message should be delivered to node i in location l before time t. Unicast with approximate location means sending a message to node i before time t1 while that node was last known to be at location l with mobility ***m*** at time t2. Multicast means disseminating a message to all receivers in region r before time t. Anycast means disseminating a message to one among a set of possible destinations (e.g., send to any police car) in region r before time t. A scan is to have a message traverse region r once before time t. In these services, location l and region r are used to direct the message to a geographical area. Time t is determined by the nature of the message, e.g., when the information becomes obsolete and serves to avoid the infinite looping of messages in the system. Other services can also be designed as variations or combinations of the above services.

To illustrate an application using these services, consider a vehicle (or a traffic signal controller) wishing to obtain information concerning some remote region. The vehicle/controller needing the information first queries its own proximity (multicast) to determine if a nearby vehicle happens to have this information. Any vehicle having such information can respond (unicast with approximate/precise location). If no one replies within a certain amount of time, the vehicle/controller sends a query to any vehicle in the remote region (anycast). Receivers in the remote region with this information can respond. The response can be disseminated as unicast with approximate/precise location or multicast if caching is desired. This scenario describes a pull approach. A push approach could also be used, e.g., vehicles encountering a crash or traffic congestion may send this information to a region-using multicast.

Another application is mobile Internet access. Fixed location Internet gateways may be placed along roads. A vehicle wishing to access the Internet first propagates a query through a region for gateways (scan). Gateways receiving the query can respond to the requesting vehicle (unicast with approximate location). The requesting vehicle picks one responder and begins to interact with it. The communication from the vehicle to the gateway is unicast with exact location, while the reverse direction is unicast with approximate location.

1. Data Delivery Mechanisms

Data delivery mechanisms define the rules for moving information through the network. Conventional data delivery services often implicitly assume that the network is connected. The “node-centric" approach [14] specifies the routing path as a sequence of connected nodes. However, the high vehicle mobility in V2V networks will quickly render inter-node connections invalid. The “location-centric" approach [15] decouples the routing path from the intermediate nodes, and the message is forwarded to the next hop (s) closer to the destination geographically. If a hole is encountered, efforts are made to find a path around it. When the network is partitioned (or at least non-continuously connected), and no direct end-to-end path is available, this approach also fails. Even broadcast protocols, e.g., gossip protocols [16], do not ensure reliable delivery in partitioned networks. “ Opportunistic forwarding” as suggested in [17], targets networks where an end-to-end path cannot be assumed to exist. Messages are stored and forwarded as opportunities present themselves. When a message is forwarded to another node, a copy may remain with the original and be forwarded again later to improve reliability. Some simple implementations, e.g., two nodes exchanging data whenever they can communicate; work well if the data needs to be propagated to everybody.

Nevertheless, they could be more efficient if a message is to be delivered to some specific receivers, e.g., those in a particular region. In this case, forwarding messages in a way that they migrate closer to the eventual destination and not to others is more efficient. "Trajectory-based forwarding" directs messages along predefined trajectories. It was presented to work well in a dense network. Despite their sparseness, V2V networks should be a natural application of trajectory-based forwarding because messages are moving along the road graph. Trajectory forwarding can help limit data propagation along specific paths and thus reduce message overhead.

2. Definition of MDDV

MDDV is a "mobility centric" approach [2] that combines opportunistic forwarding, geographical forwarding, and trajectory-based forwarding. A forwarding trajectory is specified as extending from the source to the destination (trajectory base forwarding), along which a message will be moved geographically closer to the destination (geographical forwarding). With an opportunistic forwarding approach, rules must be defined to determine who is eligible to forward a message when a copy of the message should be passed to another vehicle.

3. Assumptions

The authors assumed a vehicle knew the road topology through a digital map and its own location in the road network via a GPS device. In addition, they assumed vehicles knew the existence of their neighbors through some link-level mechanism. No assumption was made that a vehicle knows the location of its neighbors (unlike most geographic forwarding algorithms). In this way, a vehicle's knowledge of other vehicles is limited to help alleviate privacy and security concerns. Further, all instrumented vehicles were assumed to communicate using the same wireless channel. The message dissemination information (source id, source location, generation time, destination region, expiration time, and forwarding trajectory) is specified by the data source and is placed in the message header.

4. Forwarding Trajectory

A forwarding trajectory is specified as a path extending from the source to the destination region. The road network can be abstracted as a directed graph, with nodes representing intersections and edges representing road segments.

Geographical forwarding attempts to move the message geographically closer to the destination. For an ad-hoc network deployed in a two-dimensional area, geographical distance is often defined as Cartesian distance. However, in V2V networks, geographical distance has to be defined as graph distance [18]. One of the MDDV objectives is to deliver messages to their destination regions as soon as possible. A naive approach would be taking the path with the shortest distance from the source to the destination region. However, information propagation along a road depends largely on the vehicle traffic on it, e.g., vehicle density. A short road distance may not translate to a short information propagation delay. High vehicle density often leads to fast information propagation. Therefore, the road distance and traffic conditions must be considered. Nevertheless, vehicle traffic conditions change over time and vary between road segments. Here, we only explore the static road network topology information since road networks are typically engineered to match transportation demands. When the traffic information is available, it can be utilized to generate more accurate metrics. The number of lanes gives some indication of the expected vehicle traffic. The term *d(A, B)* is defined as the "dissemination length" of a road segment from road node *A* to *B*, which takes into account the static road information. Let *r(A, B)* be the road length between A and B, i/j the number of lanes from *A/B* to *B/A*. The authors used the following heuristic formula:

$$d\,(A, B) = r(A, B)(m - (m - 1)(i\,p + cj\,p \quad 0<c<1 \tag{3}$$

From reference [19], the vehicle traffic in both directions on a two-way road can help propagate information. However, the traffic in the opposite direction of the desired information flow is less helpful than the traffic in the same direction of the information flow. Constant c is used to discount the opposite traffic flow. When i = 1 and j = 0, *d(A, B) = r(A, B).* In our study, we set m = 5, p = 0.1 and c = 0.05.

Global Behavior. The dissemination process consists of two phases: forwarding and propagation. In the forwarding phase, the message is forwarded along the forwarding trajectory to the destination region. Once the message reaches the destination region, the propagation phase begins, and the message is propagated to every vehicle in an area centered on the destination region before the message time expires. This area covers the destination region and is usually more prominent for delivering the message to intended receivers before they enter the destination region to reduce delay.

Ideal Scenario. In this case, it was assumed that every vehicle has perfect knowledge concerning the global status of data dissemination. During the forwarding phase, the authors called the message holder closest to the destination region along the forwarding trajectory the “message head”. The vehicle taking the role of the message head may change over time as the message propagates or vehicles move. With perfect knowledge, every vehicle knows the message head vehicle in real-time. Only the message head tries to pass the message to other vehicles that may be closer to the destination region. During propagation, the message is propagated to vehicles without the message in the specified area.

Approximation. The above ideal scenario cannot be implemented due to the lack of perfect knowledge of participating vehicles. Specifically, individual vehicles do not know which vehicle is the message head in real-time. For example, as illustrated in Fig.8, the current message head is vehicle 1 in a two-way traffic road. In (a), vehicle 1 may run out of the trajectory or become inoperative, of which vehicle 2, the immediate follower, may not be aware because the network is partitioned. In (b), vehicle 1 moves away from the destination region (note the road is bi-directional). Once vehicle 1 passes vehicle 2, vehicle 2 should become the new message head. However, vehicle 2 does not know this unless it receives an explicit notification from vehicle 1. With our assumption that vehicles do not know the location of others, this is difficult to do.

In both cases, the message is lost. To address this problem, the authors allow a group of vehicles near the real message head to actively forward the message instead of the message head vehicle only. The group membership changes as the message head moves toward the destination region. There is a tradeoff between delivery reliability and message overhead: larger groups mean higher delivery reliability but higher message overhead too.

Vehicles must locally determine their actions based on their approximate knowledge of the global message dissemination status.

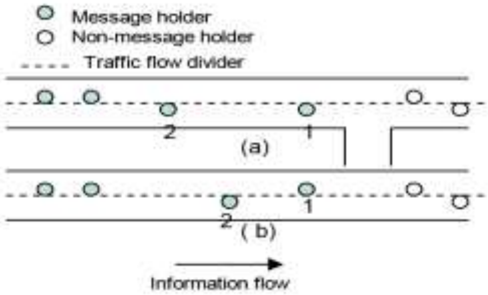


Figure 8: Lack of Perfect Knowledge

5. Store and Drop Messages

An opportunistic forwarding mechanism must determine when to store/drop a message. The design decision can affect delivery reliability, memory usage, and message overhead. The decision to store/drop messages can be based on a vehicle' s knowledge of its future movement trajectory. For example, if the vehicle is aware of its own near future movement trajectory, a message holder may decide to drop a message if it knows that continually holding the message can no longer contribute to suppress unnecessary message transmissions based on its future movement trajectory. In MDDV, every vehicle stores whatever it overhears since this is almost free except occupying memory buffers. A vehicle drops a message when the vehicle leaves the passive state during the forwarding phase, leaves the active state during the propagation phase or the message expiration time elapses. Every vehicle maintains three lists as shown in Fig.9.

The neighbors of the vehicle are stored in the neighbor list in increasing order of the time when they first appeared (firstAppearTime). A vehicle maintains a message record for every valid message overheard. Each message record includes lastHeardTime, scheduledTime, messageHeadPair, and disseminationState, among others. The meaning of these variables should be self-explanatory. The opportunistic message list stores messages not scheduled to transmit but can be transmitted when new neighbors appear. The messages in the opportunistic message list are ordered increasingly in the latest time they were transmitted or heard (lastHeardTime). The scheduled message list stores messages scheduled to transmit at some specific time. The messages in the scheduled message list are ordered increasingly in their scheduled time (scheduled Time).

Figure 9: Data Structure

Vehicles transmit messages in the opportunistic message list to new neighbors. The steps that describe this procedure are listed below, where the message ***m*** is either transmitted to other node or inserted in the message list, based on the input variable (the time).

```
Search for stored message m, the one with the smallest lastHeardTime among those with disseminationState = Active in the opportunistic message list
Search for neighbor n, the one with the largest firstAppearTime
If(m.lastHeardTime < n.firstAppearTime){
    Transmit m
    m.lastHearTime = now
    Insert m to the end of the opportunistic message list
}
```

A vehicle runs the above algorithm periodically to avoid dominating the wireless channel and allow time to hear transmissions from others. During each pass, at most one message is transmitted. A vehicle only transmits a message if new neighbors have appeared since the last time it heard/transmitted the message. Consider the following scenario. When a vehicle approaches a vehicle cluster, it becomes the neighbor of many other vehicles. However, only one vehicle will transmit a message to the newcomer, while others will suppress their transmissions of the same message upon overhearing the transmission. A vehicle runs the following pseudo code, Fig.10, when receiving a message ***m***':

The pseudo code of the MDDV routing protocol in VANET

```
Begin: (input is m, which is the coming message); (output is where to insert m in message list)

Search for stored message m which only differs m’ in the message head pair at most
    If(m does not exist){

                -   Create a message record m = m’
                    m.lastHeardTime = now
                            if(m.disseminationState = Active){
                                m.scheduledTime = now + random backoff
                                Insert m in the scheduled message list}
Else {
                        Insert m to the end of the opportunistic message list }
                      }

                Else {
                        m.lastHeardTime = now
    Compare m.messageHeadPair and m’.messageHeadPair
                if(m is significantly older than m’){
                    m.messageHeadPair = m’.messageHeadPair
                    if(m.disseminationState = Active){
                            m.scheduledTime = now + random backoff
                Insert m in the scheduled message list}

Else {
                            Insert m to the end of the opportunistic message list }}
```

```
else if(m is significantly newer than m'){
        if(m has not already been scheduled)
        m.scheduledTime = now + random backoff }
Insert m in the scheduled message list}
Else {
        Insert m to the end of the opportunistic message list
    }
  }
```

Figure 10: Pseudo code of MDDV protocol.

The above pseudo-code indicates a transmission is scheduled when a new message or a significantly different message version is received. The transmission is delayed by a random amount of time to allow the vehicle to hear others. Receiving a similar message version will not trigger transmission.

The MDDV is based on reducing message overhead. Specifically, it borrows heavily from the techniques to solve the broadcast storm problem in the case of a huge number of VANET routing traffic messages, enhancing delivery efficiency. However, it still has shortcomings: it must differentiate between message types and forward surplus messages, knowing their relevance. So, the designed relevance-based approach is implemented for the VANET network as the speed of vehicles are very high, and they have limited time to exchange message, so they forward only relevant and important messages and discard the low-priority messages. When a network disconnection occurs, nodes carry the packet with them and forward the packet to the nearest neighbor that moves into its vicinity or communication range. Fig.11 illustrates the forwarding strategy of the MDDV protocol.

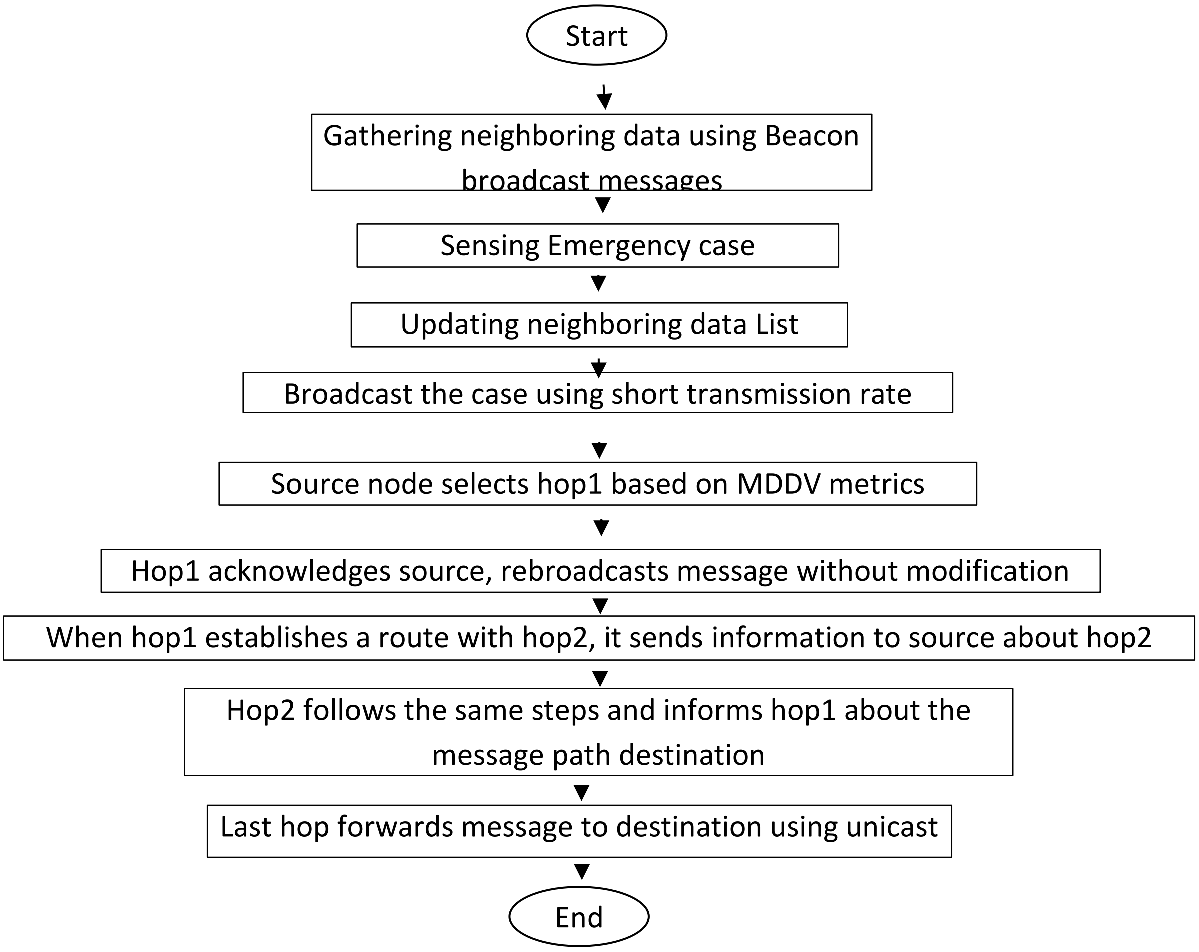


Figure 11: The forwarding strategy of the MDDV protocol.

In short, MDDV is a multi-hop protocol that uses broadcast messages to build a routing table and unicast transmission to forward packets when reaching the destination region. The distance between nodes plays an important variable; the source node selects the nearest node as the next hop, whereas the carrier node selects the geographically closer node to the destination. The end-to-end delay is not an issue in the procedure of MDDV.

6. Evaluation metrics:

6.1 Throughput:

Throughput is described as the ratio of the number of packets sent and received to the total required time using the equation as [20]:

$$\textbf{Throughput} = \frac{\textbf{Total number of sent and received packets}}{\textbf{Time}} \qquad (4)$$

6.2 End-to-End Delay:

End-To-End (ETE) delay is the difference in time from the generation of a packet at the source to the moment when it is received at the sink [8].

ETE= Src packet time- Dest packet time (5)

6.3 Packet Delivery Ratio (PDR):

Packet Delivery Ratio (PDR) is the ratio of total number of data packets received at the sink to the total number of data packets transmitted by the source. It is calculated as [8]:

$$\text{PDR} = \frac{\text{Number of packets received at sink}}{\text{Total number of packets sent}} \qquad (6)$$

6.4 Goodput :

Goodput means the total number of successfully received packets at the sink during a certain time [21].

$$\text{Goodput} = \frac{\text{Total number of received packets at sink}}{\text{Time}} \qquad (7)$$

6.5 Packet Loss Ratio:

It represents the ratio of the number of lost packets to the total number of sent packets. Each packet has a deadline before which it must be executed, and if this is not possible, the scheduler tries to minimize the number of lost packets due to deadline expiry [3].

6.6 Network density:

Network node density is the number of vehicles driving concurrently on the road. It greatly impacts the performance of VANET networks by influencing factors such as capacity, routing efficiency, delays, and robustness [3].

$$\text{Network density} = \frac{\text{Number of Vehicles}}{\text{Road Segment Length}} \qquad (8)$$

7. Implementation, Results and Discussion

7.1 Implementation

To implement the two routing protocol, a network environment consisting of SUMO, VEINS, and INET++ libraries within the OMNeT++ core simulator is available in the present study. OMNeT++ (Objective Modular Network) is adopted in the present work due to its desired features: extensible, modular, component-based C++ object-oriented. OMNeT++ represents a framework technology; it does not provide direct simulation components for computer networks. Instead, it provides the basic machinery and tools to write the required simulations [22]. Several libraries can be integrated with OMNet++, including INET, VEINS, and SUMO.

INET provides communication libraries such as routing protocols and wireless technologies. VEINS (Vehicles in network simulation) provide cars and road network libraries to create VANETs and serves as the main bases for writing application-specific simulation code [23]. SUMO (Simulator of Urban Mobility) provides a variety of tools with the ability to generate, execute, and evaluate traffic simulations [24, 25], as explained in Fig.12.

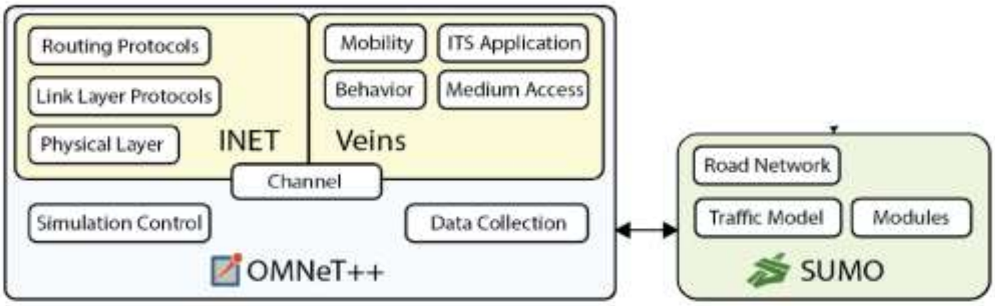


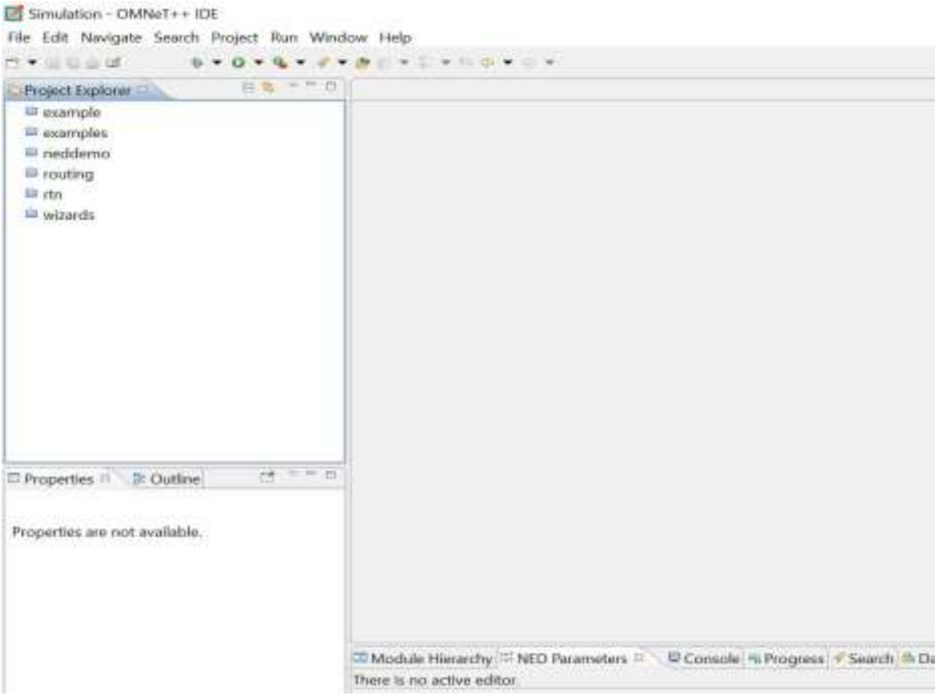
Figure 12: Integration of INET, VEINS and SUMO with OMNeT++.

The two protocols have been implemented in an environment with the specifications shown in Table 1. The codes of the protocols are written in C++ of OMNET++ 4.6 simulation tool.

Table 1: Environment specifications

Operating Systems	Windows 10, 64-Bit
CPU	Core (TM) i3-1005G1
RAM	8.00 GB
Implementation Tools	OMNET++ 4.6, INET 3.3.0, VEINS and SUMO
Node Speed	90 km/hr
Direction	All nodes move in the same direction.

The OMNET++ framework should be installed on the root of the storage unit (usually on C:), which includes some default folders, as shown in Fig.13.

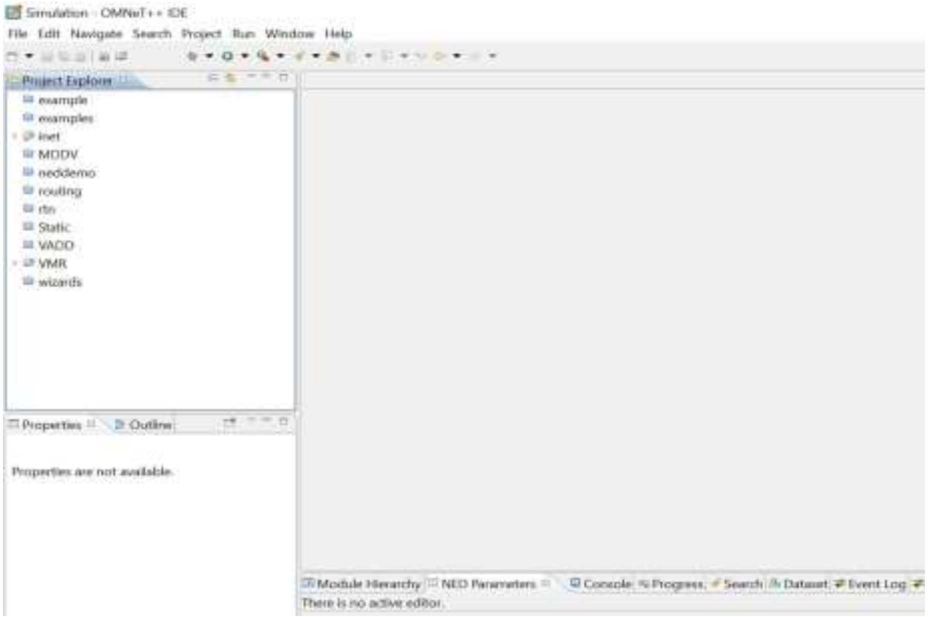


Properties are not available.

There is no active editor.

Figure 13: The main interface of OMNET++ framework.

The C++ codes of the routing protocols (MDDV, VADD) must be prepared and inserted in the project explorer. The codes can be written in C++ Environment or even inside OMNET++. The INET library is also installed in the same place, as shown in Fig.14.



Properties are not available.

There is no active editor.

Figure 14: Project Explorer interface after adding routing protocols and INET.

Results and Discussion

1. Scenario of MDDV Routing Protocol

The 1st implemented case is based on the MDDV protocol. As mentioned, MDDV is a multi-hop routing protocol that relies on delay and the short distance between the source and carriers. Table 2 illustrates the metrics of the MDDV routing system based on 8 OBUs nodes. The average PDR with 8 OBUs is 98.42207%. Total sum of goodput is 40.334 pkt/s. The end-to-end delay for vehicle-to-RSU is 822862.146 ms, and RSU-to-Server is 762388.698 ms.

Table 2: The MDDV routing protocol packet delivery with 8 OBUs.

Network Elements	Throughput / Bps		End to End Packet Delay (ms)		Packet Delivery Ratio (%)	Goodput pkts/sec
	Frames/sec Sent	Frames/sec Received	OBUs-To-RSUs	RSUs-To-Server		
OBU 1	121.7664	121.7328	55808.57	62688.67	99.9724	2.181256
OBU 2	119.392	118.5968	54516.58	51559.6	99.334	2.175426
OBU 3	120.512	116.6928	54526.92	59683.85	96.8309	2.140095
OBU 4	120.7024	119.4256	53357.49	52252.63	98.9422	2.238216
OBU 5	17.3712	17.36	7795.476	8607.506	99.9355	2.226933
OBU 6	120.8368	118.9552	13942.33	5968.622	98.4429	8.531946

OBU 7	120.9488	118.0704	16465.42	59684.17	97.6202	7.17081
OBU 8	92.176	85.2544	14532.59	52678	92.4909	5.866428
RUS 1 (Avg)	98.62776	98.252	30705.14	28112.04	99.619	3.199855
RUS 2 (Avg)	84.2819	83.9608	26238.93	24023.01	99.619	3.199856
Server	695.7328	694.5904	494972.7	357130.6	99.8358	1.40329
Packet Size	1024 Byte					

Table 3 shows the evaluation metrics of the MDDV system based on 16 vehicle nodes. The average of MDDV route PDR with 16 OBUs vehicles is 96.3934 %, and goodput is 46.59211 packets in sec. End-to-End Packet Delay Vehicle-to-RSU is 788990.79 ms, whereas it is 762987.2 ms from RSU-to-Server. In addition, the total throughput of the sent packets is 1415.00092 frames in seconds; for received packets, the throughput is 1374.70632 Frames/sec.

Table 3: The MDDV route packet delivery with 16 OBUs vehicles.

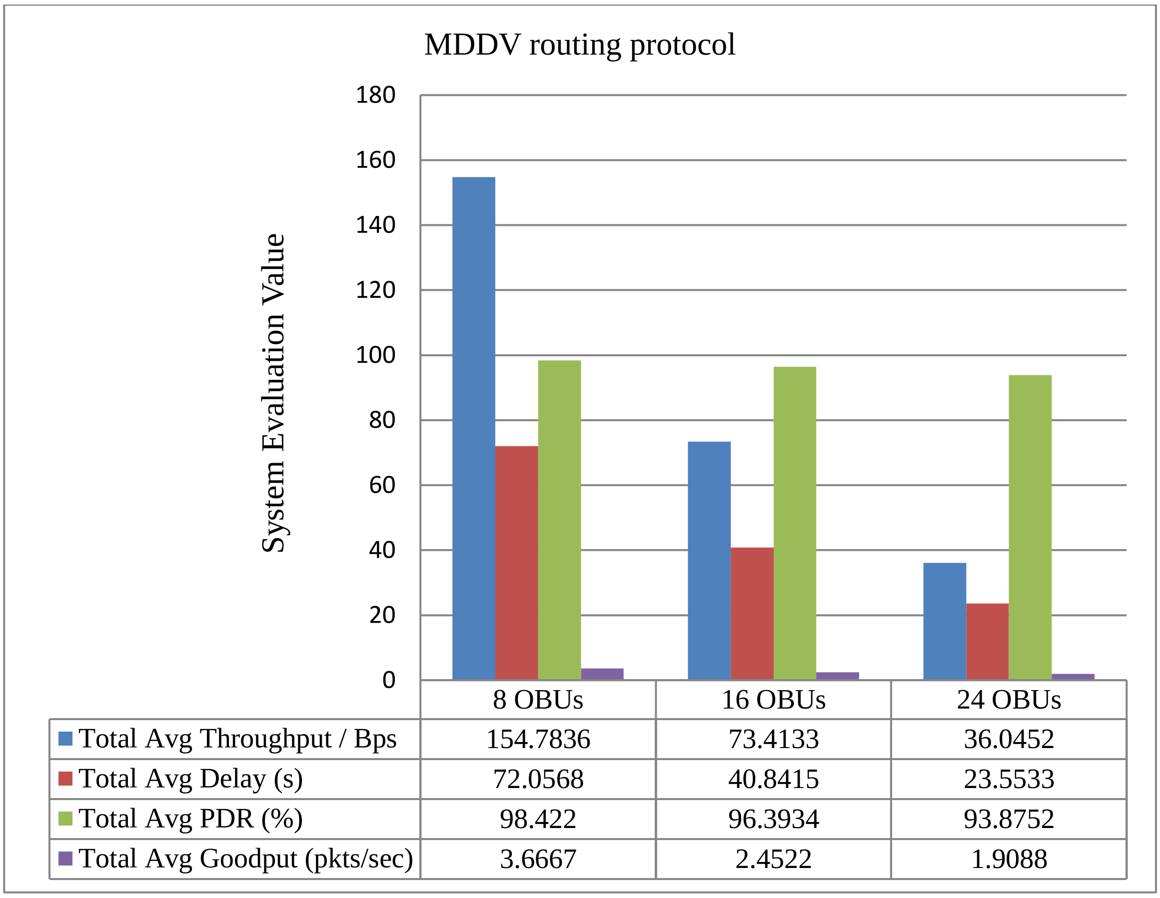
Network Elements	**Throughput / bps**		**End to End Packet Delay (ms)**		**Packet Delivery Ratio (%)**	**Goodput pkt/s**
	Sent	**Received**	**OBUs-To-RSUs**	**RSUs-To-Server**		
OBU 1	57.09424	55.94512	19628.65	19432.36	97.9873	1.430508
OBU 2	54.64704	53.54048	19236.07	19043.71	97.9751	1.816068
OBU 3	56.84952	55.7004	19039.79	18849.39	97.9787	1.447399
OBU 4	56.48776	55.34928	20021.22	19620.79	97.9846	2.42013
OBU 5	63.55272	62.27592	20413.79	20005.51	97.991	2.850177
OBU 6	48.95464	47.99704	19824.94	19230.18	98.0439	2.783338
OBU 7	51.06136	50.02928	19039.79	18468.6	97.9787	2.925473
OBU 8	45.5392	44.62416	17665.78	17135.81	97.9907	2.764531
OBU 9	50.8592	49.83776	18843.51	18278.19	97.9916	3.050679
OBU 10	57.1368	54.82792	20806.37	19557.99	95.959	2.421043
OBU 11	43.4644	42.59192	17489.12	16439.79	97.9927	2.627617
OBU 12	70.10696	67.54272	21638.61	19907.53	96.3424	2.526023
OBU 13	28.96208	26.068	14515.97	13354.7	90.0073	2.644824
OBU 14	29.35666	29.134	16661.98	15828.88	99.2415	2.635151
OBU 15	31.85851	30.51451	16995.23	16145.46	95.7813	2.435338
OBU 16	21.53323	19.29323	13329.59	12663.11	89.5975	3.121398
RSU 1 (Avg)	42.92443	40.09289	12734.32	12352.29	93.4034	3.148412
RSU 2 (Avg)	36.68087	34.29549	10882.06	10555.59	93.4969	1.748532
Server	567.9313	555.0462	470224	456117.3	97.7312	1.795475
Packet Size	1024 Byte					

Table 4 presents the evaluation metrics of the MDDV protocol for the case of 24 OBUs. The total sum PDR (%) of the MDDV route packet delivery with 24 OBUs is 93.8752 %, and the total sum of goodput is 51.5398 pkt/s.

Table 4: The MDDV route packet delivery with 24 OBUs.

Network Elements	**Throughput / bps**		**End to End Packet Delay (ms)**		**Packet Delivery Ratio (%)**	**Goodput pkt/s**
	Sent	**Received**	**OBUs-To-RSUs**	**RSUs-To-Server**		
OBU 1	29.67496	29.3664	13347.48	13214	98.9602	2.200146
OBU 2	28.4088	28.12152	13080.52	12949.71	98.9888	2.149878
OBU 3	29.55792	28.96208	12947.05	12688.1	97.9842	2.236964
OBU 4	29.35576	28.77056	13614.42	13342.12	98.0065	2.113242
OBU 5	33.0372	32.03704	13881.37	13464.93	96.9726	2.307916
OBU 6	25.45088	24.6848	13480.95	13076.52	96.99	1.831088
OBU 7	26.5468	25.73816	14977.39	14528.07	96.9539	1.718468
OBU 8	23.674	22.72704	12012.74	11652.36	96.0	1.891911
OBU 9	26.4404	25.36576	13828.74	13137.3	95.9356	1.834278
OBU 10	29.70688	28.20664	14148.33	13440.91	94.9499	1.993637
OBU 11	22.58872	21.45024	11892.6	13440.91	94.96	1.803663
OBU 12	36.442	33.87776	14714.26	13978.53	92.9635	2.302376
OBU 13	15.04496	13.9916	9870.859	9377.314	92.9986	1.417465
OBU 14	29.67496	27.58952	13347.48	12012.73	92.9724	2.067021
OBU 15	28.4088	26.13184	13080.52	11772.48	91.985	1.997768
OBU 16	29.55792	26.6	12947.05	11652.35	89.9928	2.054522
OBU 17	29.93032	26.9192	13614.42	12252.98	89.9396	1.977256
OBU 18	30.49424	27.4512	13881.37	12493.23	90.0209	1.977557
OBU 19	23.49312	21.14168	13480.95	12132.85	89.9909	1.568263
OBU 20	24.50392	22.04608	12947.05	11652.35	89.9696	1.702788
OBU 21	21.84392	19.65208	12012.74	10811.45	89.9659	1.635937
OBU 22	24.40816	21.96096	12813.57	11532.21	89.9738	1.713883
OBU 23	27.40864	24.66352	14148.33	12733.49	89.9845	1.743211
OBU 24	18.90444	17.23319	11145.09	10030.57	91.1595	1.546258
RSU 1 (Avg)	23.50515	22.3206	9217.676	8295.9	94.9605	2.4215
RSU 2 (Avg)	20.08621	19.09305	7876.923	7089.224	95.0555	2.423922
Server	312.3478	299.8458	329904.1	296913.6	95.9974	0.908888
Packet Size	1024 Byte					

The performance of the three cases using the MDDV protocol is presented in Fig.15. The results of MDDV as the total average throughput of 8 OBUs (154.7836) Bps, (73.4133) Bps of 16 OBUs, and (36.0452) Bps of 24 OBUs. The total average delay is decreased from (72.0568) seconds to (23.5533) seconds. Total average PDR is decreased from (98.4220) % to (93.8752) % due to the decreased number of successfully arrived data packets from the vehicles to the final destination. The total average goodput is decreased from (3.6667) to (1.9088) pkt/s due to a decreased number of acknowledgment packets from the receiver node.



	8 OBUs	16 OBUs	24 OBUs
🟦 Total Avg Throughput / Bps	154.7836	73.4133	36.0452
🟥 Total Avg Delay (s)	72.0568	40.8415	23.5533
🟩 Total Avg PDR (%)	98.422	96.3934	93.8752
🟪 Total Avg Goodput (pkts/sec)	3.6667	2.4522	1.9088

Figure15: Effect of node density on MDDV routing protocol performance.

2. Scenario of Vehicle-Assisted Data Delivery (VADD) Routing Protocol

As discussed earlier, the VADD protocol is based on the carry and forward strategy; each node carries the packet when routes do not exist and forwards the packet to the new receiver that moves into its vicinity. It was used to efficiently route the packet to that site and receive the reply within a reasonable delay, so it uses the predictable mobility in a VANET depending on the OBUs connectivity. It serves as a performance benchmark with delay lower-bound. It decreased the time required to build a route between OBUs vehicles to the RSUs and RSUs to the demand server to provide a better routing performance than the static technique. In this scenario, RSU is responsible for collecting the original information, selecting the next road (intersection) of vehicle nodes, and forwarding the processed results to the server outside the region for more processing as the next step of collecting vehicle data.

It is used in the case of a huge number of vehicles due to the protocol's behavior to build the best route based on average speed, node density, distance, and minimum delay. The packets are then redirected among other nodes regardless node was OBU or RSU. As mentioned, the main challenge of VADD is looping, and it is one-hop forwarding.

Table 5 lists the metrics of the VADD routing system based on 8 OBUs vehicles. As can be seen, the results represented an enhancement compared with MDDV protocol due to the behavior of this protocol. The PDR of the VADD route with 8 OBUs is (98.9961%). The total sum of goodput is (43.6671) packets in seconds. End-to-end packet delay OBUs-to-RSUs is (801062.4) ms, and RSUs-to-Server is (748038.9) ms.

Table 5: The VADD route packet delivery with 8 OBUs.

Network Elements	**Throughput / bps**		**End to End Packet Delay (ms)**		**Packet Delivery Ratio (%)**	**Goodput pkt/s**
	Sent	**Received**	**OBUs-To-RSUs**	**RSUs-To-Server**		
OBU 1	128.184	128.1504	54183.08	60862.7936	99.9738	2.365137
OBU 2	125.6864	124.8464	52928.7248	50057.8624	99.3317	2.358765
OBU 3	126.8624	122.8416	52938.76	57945.4848	96.8306	2.320447
OBU 4	127.064	125.72	51803.3936	50730.7024	98.9423	2.426868
OBU 5	18.2896	18.2784	7568.4224	8356.8016	99.9388	2.415087
OBU 6	127.1984	125.216	13536.2416	5794.7792	98.4415	9.250426
OBU 7	127.3216	126.2864	15985.8496	57945.7984	99.1869	7.899887
OBU 8	103.2371	100.48493	16276.5008	58999.36	97.3341	6.17362
RUS 1 (Avg)	103.8206	103.323	29810.8048	27293.2464	99.5207	3.465958
RUS 2 (Avg)	88.71946	88.38256	25474.6912	23323.3168	99.6203	3.469426
Server	732.3568	731.1584	480555.9808	346728.76	99.8364	1.521484
Packet Size	1024 Byte					

Table 6 shows the evaluation metrics of the VADD system based on 16 OBUs nodes. The average VADD route packet delivery with 16 nodes (97.2121%) is enhanced over MDDV, and the total sum goodput is (51.0077) packets in sec. Besides, the end-to-end packet delay vehicle-to-RSU is (773017.5) ms, while it is (747420.8) ms from RSU-to-Server. In addition, the Total sum Throughput sent is (1495.049) frames in seconds, and besides received is (1458.377) Frames/sec.

Table 6: The VADD route packet delivery with 16 OBUs vehicles.

Network Elements	**Throughput / bps**		**End to End Packet Delay (ms)**		**PDR (%)**	**Goodput pkt/s**
	Sent	**Received**	**OBUs-To-RSUs**	**RSUs-To-Server**		
OBU 1	60.0992	58.8896	19056.9456	18866.3664	0.979873	3.090191
OBU 2	57.5232	56.3584	18675.7984	18489.0384	0.979751	3.017724
OBU 3	59.8416	58.632	18485.2304	18300.3744	0.979787	3.17183
OBU 4	59.4608	58.2624	19438.0816	19049.3072	0.979846	2.997333
OBU 5	66.8976	65.5536	19819.2176	19422.8272	0.97991	3.307578
OBU 6	51.5312	50.5232	19247.5136	18670.0752	0.980439	2.624921
OBU 7	53.7488	52.6624	18485.2304	17930.6736	0.979787	2.848891
OBU 8	47.936	46.9728	17151.2432	16636.704	0.979907	2.73874
OBU 9	53.536	52.4608	18294.6624	17745.8176	0.979916	2.867547
OBU 10	60.144	59.7136	20200.3648	18988.3344	0.992844	2.956065
OBU 11	45.752	44.8336	16979.7376	15960.952	0.979927	2.640418
OBU 12	73.7968	71.0976	21008.3664	19327.6944	0.963424	3.384252
OBU 13	30.4864	28.44	14093.1728	12965.7248	0.932875	2.017998
OBU 14	32.8794592	32.63008	18661.4176	17728.3456	0.992415	1.748532
OBU 15	35.6815312	34.1762512	19034.6576	18082.9152	0.957813	1.795475
OBU 16	24.1172176	22.6084176	14929.1408	14182.6832	0.937439	1.514382
RSU 1 (Avg)	45.1836	43.20303	12363.4224	11992.512	0.956166	3.494423
RSU 2 (Avg)	38.61144	37.100512	10565.1056	10248.15008	0.960868	3.511608
Server	597.8224	584.2592	456528.184	442832.3312	0.977312	1.279788
Packet Size	1024 Byte					

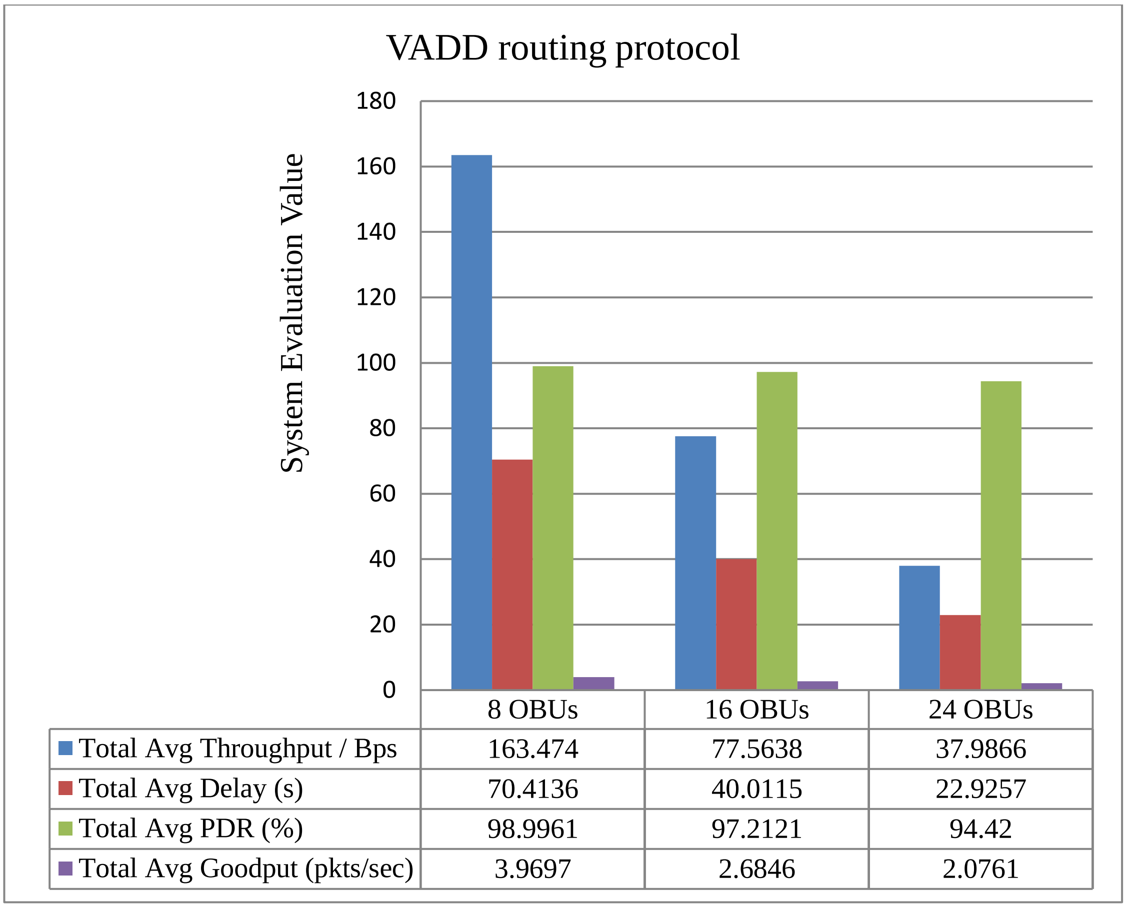
The performance of VADD for 24 nodes is given in Table 7. The average PDR with VADD 24 OBUs nodes is (94.42)%, while the total sum of goodput is (56.0551) packets in seconds.

Table 7: The VADD route packet delivery with 24 OBUs.

Network Elements	**Throughput / bps**		**End to End Packet Delay (ms)**		**Packet Delivery Ratio (%)**	**Goodput pkt/s**
	Sent	**Received**	**OBUs-To-RSUs**	**RSUs-To-Server**		
OBU 1	31.2368	30.912	12958.7136	12829.1184	98.9602	2.385422
OBU 2	29.904	29.6016	12699.5344	12572.5376	98.9888	2.33092
OBU 3	31.1136	30.4864	12569.9504	12318.544	97.9842	2.42534
OBU 4	30.9008	30.2848	13217.8816	12953.5168	98.0065	2.291199
OBU 5	34.776	33.7232	13477.0608	13072.752	96.9726	2.502267
OBU 6	26.7904	25.984	13088.2976	12695.648	96.99	1.985285
OBU 7	27.944	27.0928	14541.1504	14104.9216	96.9539	1.863181
OBU 8	24.92	23.9232	11662.8512	11312.9632	96.0	2.051231
OBU 9	27.832	26.7008	13425.9664	12754.6608	95.9356	1.988743
OBU 10	31.2704	29.6912	13736.24	13049.4224	94.9499	2.161523
OBU 11	23.7776	22.5792	11546.2144	13049.4224	94.96	1.95555
OBU 12	38.36	35.6608	14285.6896	13571.3872	92.9635	2.49626
OBU 13	15.8368	14.728	9583.3584	9104.1888	92.9986	1.536831
OBU 14	31.2368	29.0416	12958.7136	11662.84	92.9724	2.241087
OBU 15	29.904	27.5072	12699.5344	11429.5888	91.985	2.166001
OBU 16	31.1136	28	12569.9504	11312.952	89.9928	2.227535
OBU 17	31.5056	29.336	13217.8816	11896.0912	93.1136	2.219418
OBU 18	32.0992	28.896	13477.0608	12129.3536	90.0209	2.144088
OBU 19	24.7296	23.2544	13088.2976	11779.4656	94.0347	1.776732
OBU 20	25.7936	23.2064	12569.9504	11312.952	89.9696	1.846181
OBU 21	22.9936	21.6864	11662.8512	10496.5504	94.3149	1.859442
OBU 22	25.6928	23.1168	12440.3664	11196.3264	89.9738	1.858209
OBU 23	28.8512	26.9616	13736.24	12362.616	93.4505	1.962808
OBU 24	21.1729728	19.3011728	12482.5008	11234.2384	91.1595	1.546258
RSU 1 (Avg)	24.742256	23.4485	8949.19872	8054.27392	94.7711	2.620179
RSU 2 (Avg)	21.1433824	20.097952	7647.49664	6882.74272	95.0555	2.628043
Server	328.7872	315.6272	320295.1584	288265.6448	95.9974	0.985426
Packet Size	1024 Byte					

Fig.16 compares three states of the VADD routing protocol system. The results of the VADD route are better than those of the MDDV route due to avoiding broadcast transmission. The average throughput of 8 OBUs VADD route is (163.474) bps, (77.5638) bps for 16 OBUs, and (37.9866) bps for 24 OBUs. The decrease is due to the increased number of OBUs nodes affecting the total generated packets from vehicles.

The total Average Delay in seconds is decreased from (70.4136) seconds to 22.9257 seconds because the active vehicle takes the connection to transmit data and waits for reply from dedicated servers. Total average PDR decreased from (98.9961)% to (94.42)% due to the decrease in the number of arrived packets (resulting from the high number of vehicles). For the same reason, the total average goodput (pkt/s) is decreased from (3.9697) to (2.0761) packets in seconds.



	8 OBUs	16 OBUs	24 OBUs
🟦 Total Avg Throughput / Bps	163.474	77.5638	37.9866
🟥 Total Avg Delay (s)	70.4136	40.0115	22.9257
🟩 Total Avg PDR (%)	98.9961	97.2121	94.42
🟪 Total Avg Goodput (pkts/sec)	3.9697	2.6846	2.0761

Figure 16: Comparison of the VADD route cases.

Comparison

Fig.(17) compares the performance of the two protocols for the four parameters. All the sub-figures reveal that for vehicle density of 8, MDDV gives better results.

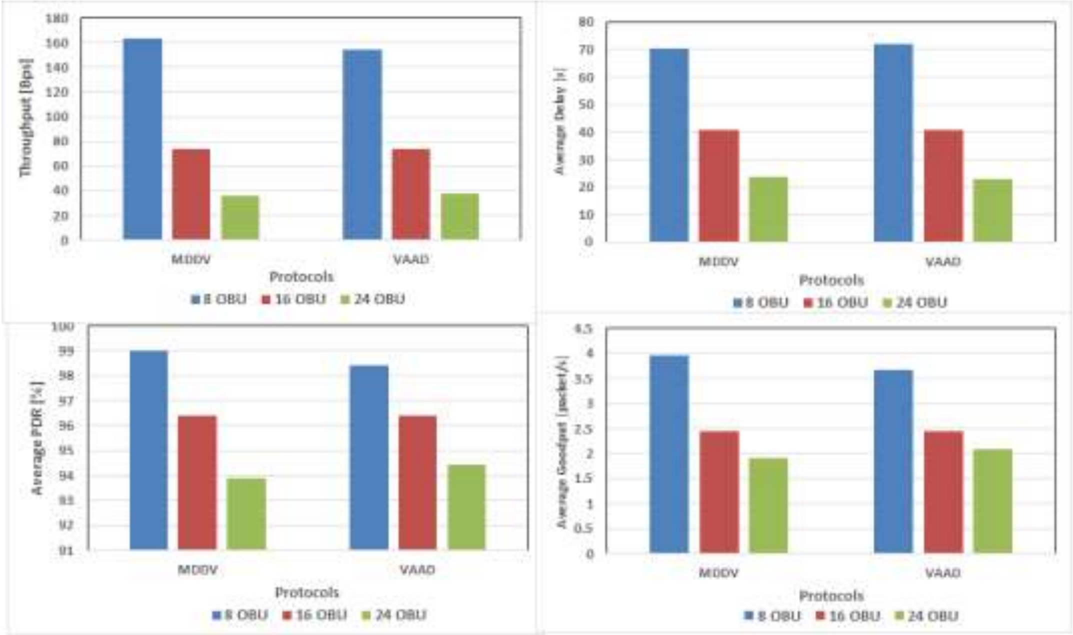


Figure 17: Performance Comparison of VADD and MDDV.

For 16 OBUs, both protocols show approximately the same results. When the density increases to 24 nodes, VADD yields better performance. It is expected that the performance of VADD will be much better with increasing of nodes more than 24. As mentioned earlier, the single-hop protocols tried to reach destination with high transmission rate using one-hop, therefore it is preferable for these protocols to work in a high node density. On the other hand, the multi-hop protocols used low transmission rate and then cannot work suitably in a high -node density environment.

Conclusion

This study presents a comparison between two well-known position routing protocols, namely: VADD and MDDV. The comparison demonstrates the effect of node density on the performance of these two protocols. The OMNET++ simulator is integrated with SUMO, VIENS and INET++ libraries to provide the required environment for evaluating the protocols. The results have shown that MDDV gives higher values of throughput, packet delivery ratio, goodput and lower end-to end delay for low vehicle density. The enhancement in these parameters is about 10%. On the other hand, the performance of VADD is better for high node density in term of these parameters. The improvement in VADD prediction reaches about 15% as compared to MDDV. As a conclusion of this study, the single-hop VADD protocol is suitable for high vehicle density, whereas the multi-hop MDDV protocol is preferable in low vehicle density environments. For future work, we will compare these two protocols using both the node density and the speed of vehicles.

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