An approach for offloading with multi-hop considerations in an RSU signal overlay setting

Uma abordagem para descarga com considerações multi-hop em uma configuração de sobreposição de sinal RSU

Un enfoque para descargar con consideraciones de saltos múltiples en un ajuste de superposición de señal RSU

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Fátima de Lima Procópio Duarte Figueiredo²

Abstract

In recent years, significant advancements in vehicle technology have spurred growing interest in Vehicular Ad hoc Networks (VANETs). This interest is driven by concerns for road safety and the need to alleviate network congestion, leading to the emergence of Intelligent Transport Systems (ITS). ITS focuses on improving road traffic management and safety through the utilization of wireless and mobile network communication technologies. VANETs play a pivotal role within the realm of ITS, facilitating tasks such as enhancing road safety, traffic monitoring, and ensuring passenger comfort by mitigating accidents and congestion. These objectives rely on the timely and accurate delivery of data to vehicle agents and relevant authorities, facilitated by reliable VANETs and Road Signal Units (RSUs). Achieving this necessitates identifying optimal routes with minimal distance, high radio access, and quality-awareness levels. To address these objectives, this study proposes the utilization of the Congestion Network with Predicted K-means multi-hop RSU algorithm (CN-MHMR) to enhance vehicular networking and communication. This algorithm facilitates efficient node transfer from base nodes to destination nodes via the shortest and energy-efficient paths, thereby enabling viable and reliable vehicular communications. The performance of the proposed model was evaluated based on various metrics, including energy consumption,

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throughput, delay, packet delivery ratio, accuracy, precision, and recall values.

**Keywords:** Vehicular Ad hoc Networks. Road Signal Units. Discrete Packets. Energy Efficient Routing. Vehicular Communication.

**Resumo**

Em anos recentes, avanços significativos na tecnologia veicular têm despertado um crescente interesse em Redes Ad hoc Veiculares (VANETs). Este interesse é impulsionado por preocupações com a segurança nas estradas e pela necessidade de aliviar a congestão de redes, levando ao surgimento de Sistemas de Transporte Inteligentes (ITS). ITS se concentra em melhorar o gerenciamento do tráfego rodoviário e a segurança através da utilização de tecnologias de comunicação sem fio e móveis. As VANETs desempenham um papel crucial dentro do domínio dos ITS, facilitando tarefas como o aprimoramento da segurança rodoviária, monitoramento do tráfego e garantia do conforto dos passageiros, mitigando acidentes e congestionamentos. Esses objetivos dependem de uma entrega oportuna e precisa de dados para agentes veiculares e autoridades relevantes, facilitada por VANETs confiáveis e Unidades de Sinalização de Estrada (RSUs). Para alcançar isso, é necessário identificar rotas ótimas com distância mínima, alto acesso de rádio e níveis de consciência de qualidade. Para abordar esses objetivos, este estudo propõe a utilização do algoritmo de Rede de Congestionamento com K-means multi-hop RSU previsto (CN-MHMR) para aprimorar a rede e comunicação veiculares. Esse algoritmo facilita a transferência eficiente de nós de nós base para nós de destino através de caminhos mais curtos e eficientes em energia, permitindo assim comunicações veiculares viáveis e confiáveis. O desempenho do modelo proposto foi avaliado com base em várias métricas, incluindo consumo de energia, throughput, atraso, taxa de entrega de pacotes, precisão e valores de recordação.


**Resumen**

En años recientes, los avances significativos en la tecnología vehicular han despertado un creciente interés en las Redes Ad hoc Vehiculares (VANETs). Este interés está impulsado por preocupaciones sobre la seguridad en las carreteras y la necesidad de aliviar la congestión de redes, lo que ha llevado al surgimiento de los Sistemas de Transporte Inteligente (ITS). ITS se enfoca en mejorar el manejo del tráfico rodado y la seguridad a través de la utilización de tecnologías de comunicación inalámbrica y móvil. Las VANETs juegan un papel crucial
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Vehicular Ad-hoc Networks, known as VANET, are vital in making an Intelligent Transportation Systems (ITS). Due to increased traffic levels, the topology in the network changes results as a dynamic challenge for the sparse vehicle distribution and relies in hindering the scalability of the network. The Multi-Access Edge Computing (MEC) is an emerging technology that enables computing and storage resources to be moved closer to the network edge. Access points or base stations are some examples that can be used to reduce the network latency and to improve data transfer efficiency. MEC can be used in various applications, including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, which allow vehicles to communicate with each other and with roadside units (RSUs) [1].

With the increasing demand for services that utilize vehicular networks and the large amount of data generated by the vehicles, it is necessary to develop strategies to alleviate the overload in these networks. Offloading is a strategy used to reduce the amount of data/services transmitted over the network. During this process, data is transmitted using Vehicle-to-Vehicle (V2V) and Vehicle-to-Road Infrastructure (V2I) communications [2]. The V2V and V2I data...
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Offloading is an important VANET problem to be solved. The use of MEC in this context can help to reduce the network load and to improve the data offloading performance [3].

Offloading to infrastructure, using V2I communications, can utilize Cellular Base Stations (CBS) or Roadside Side Units (RSUs). CBSs have higher cost per data transmitted and should be avoided. RSUs have lower cost for data traffic and are therefore preferred for V2I offloading [4]. However, while RSUs have lower data traffic costs, they are not widely available due to deployment costs. In cases where RSUs are not accessible, the offloading solution must utilize the cellular network [7]. During the offloading from the vehicular network to the infrastructure, the need for multi-hop routing may arise to ensure that the information reaches the RSU. The solution must choose the best path between the vehicle needing to offload data and the RSU. During the selection of the optimal transmission path, factors such as energy consumption, delivery success probability, and delivery time must be taken into consideration [8].

In an overlapping multi-RSU environment, multiple RSUs are deployed in an area, and vehicles can reach multiple RSUs simultaneously. This can be leveraged to improve data offloading efficiency by allowing vehicles to communicate with the RSU that provides the best connectivity at any given time [5]. The basic idea of MEC-based data offloading in an overlapping multi-RSU environment is that vehicles can offload their data to an RSU that can process the data and forward it to a MEC server located at the network edge. The MEC server can perform various tasks on the data, such as aggregation, filtering, and data analysis. After that, the MEC can send the processed data back to the RSU for delivery to other vehicles or to the cloud [6].

To implement MEC-based data offloading in an overlapping multi-RSU environment, several challenges need to be addressed, such as resource allocation, mobility management, routing and security [9]. Resource allocation involves allocating computing and storage resources to vehicles and RSUs based on their requirements and availability. Mobility management involves ensuring seamless handover of vehicles between RSUs and maintaining connectivity during the handover process. Security involves ensuring the confidentiality and integrity of data during transfer and storage. In summary, MEC-based data offloading in an overlapping multi-RSU environment has the potential to enhance the efficiency and performance of V2V and V2I communications. However, several challenges need to be overcome before this technology can be widely deployed in real-world scenarios [10].

In this context, this work presents a solution for offloading considering multiple hops for transmission and the potential overlap of RSU signals. The proposed study uses a Predicted
K-means Multiple Hop algorithm with the Congestion Network, for finding the efficient MEC for the vehicular offloading. It can also prevent congestion in the vehicular networks, and also increase the establishment of the broadcast packets and simultaneously decrease the number of discrete packets by finding the energy efficient routes for the vehicular communication [28]. These are done by evaluating the fitness of the RSU which are the intermediate in providing an uninterrupted vehicular communication. These are in a continuous iteration, until the energy efficient route is found for the efficient node transfer. These are evaluated using the appropriate performance metrics, consisting in throughput levels, delay, packet delivery ratios and levels of energy consumption, for evaluating the energy efficient path identified for the node transfer from base station to the destination.

The main goal of this paper is effective V2V2I (Vehicle-to-Vehicle-to-Infrastructure) communication. This is achieved by finding the best offloading ways, considering multiple RSUs, energy consumption and network congestion. The specific goals were: (1) the CN-MHMR algorithm implementation to evaluate the RSUs fitness function value ensuring the vehicular broadcast and the routing for the node transmission using VVR-RSU method and (2) the overall model performance evaluation through some metrics such as ratio of packet deliveries, delay time, precision, recall and also the accuracy rates.

The remaining parts of the paper are the following: section III presents some of the existing models and approaches in vehicle networking and communications, section IV, explains the solution and the methodology used, section V shows the results. Finally, section VI provides an overall conclusion and some future work.

**Review on Existing Work**

Some existing research has focused on improving the effectiveness of vehicular networking and communications, as listed in this section.

The authors of [17] proposed HetCast, a collaborative data transmission mechanism for vehicle users that utilizes both cellular LTE networks and IEEE 802.11p. The goal is to use the IEEE 802.11p network to offload LTE data traffic through RSU-based data transmission based on data popularity. The proposed method divides data into popular and unpopular categories and transmits popular data from RSUs, while unpopular data is received over LTE. The authors also proposed three schemes to establish a global transmission schedule, including an independent RSU scheduling scheme, a collaborative RSU scheduling scheme, and a collaborative RSU scheduling scheme with anticipation. Simulation results
showed that the proposed method can effectively reduce the traffic load on the LTE cellular network and improve download efficiency.

In [18], the authors proposed a QoS-aware offloading scheme to address the problem of data congestion in cellular networks. The solution offloads delay-tolerant data to vehicular network components such as vehicles and RSUs. The proposed scheme involves dividing the delay-tolerant data into equally-sized data blocks (DBs) and storing them in the current vehicle/RSU or delivering them to the next-hop device. The decision-making process of the next-hop device is formulated as an optimization problem using a partially observable Markov decision process (POMDP). Experimental results demonstrate that the authors' scheme significantly improves performance when compared to other considered schemes. The effectiveness of the scheme in alleviating congestion in cellular networks is demonstrated by its ability to offload delay-tolerant data to vehicular network resources. The use of POMDP for decision-making ensures that the next-hop device makes optimal decisions based on its partial observation of the system's state.

In [19], the authors proposed an adaptive algorithm for data offloading decision-making in vehicular networks considering both the cost and delay of cellular base stations (BS) and roadside Wi-Fi access points (APs). The algorithm was developed taking into account that users prefer free networks and desire a minimum download waiting time. To solve the decision-making problem, the proposed algorithm estimated the encounter time between a vehicle and a Wi-Fi AP, and then the vehicle chose the best download strategy based on the estimation. However, as the current situation may differ from the original estimate, for example, if a vehicle encounters a Wi-Fi AP earlier than expected, the proposed algorithm dynamically adjusted the estimated waiting time and the currently adopted offloading strategy. Experimental results showed that the proposed method can achieve better user satisfaction compared to other methods. In summary, the authors' adaptive algorithm considers user preferences and Wi-Fi AP encounter opportunities, resulting in improved data download performance in vehicular networks.

The previously mentioned works belong to the traditional V2I scenario, which means offloading considering only one hop. Our proposed work adopts a VVR (Vehicle-to-Vehicle-to-Roadside) multi-hop path to perform offloading.

In the traditional V2I scenario, offloading is performed through a direct communication link between a vehicle and an infrastructure node. This approach is often limited by the communication range of the infrastructure node and can result in network congestion and poor performance. In contrast, a multi-hop VVR path defines that vehicles
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relay the data to each other until they reach a roadside unit that can send the data to the internet or other networks. By using a multi-hop approach, the limitations of the traditional V2I scenario can be overcome, improving network performance. Vehicles can communicate with each other over longer distances, and the workload is distributed among multiple nodes, reducing the risk of congestion.

An innovative decision-making framework has been proposed for data offloading to two types of servers: terrestrial MEC servers and MEC servers mounted on unmanned aerial vehicles (UAVs), which have distinct characteristics and capabilities [20]. In this proposed scheme, users have the option to partially offload their data to a complex MEC environment, considering the latency and the energy requirements. They can use a theoretical prospective decision-making to maximize perceived utility and reduce time and energy consumption by terrestrial MEC servers. Numerical results showed that the proposed framework operates well and the method outperforms other compared methods in the study.

In [21], the authors investigated how to improve MEC access capability and increase spectrum utilization efficiency by studying the task offloading and resource allocation problem. The main idea proposed was to maximize the MEC processing capacity as an optimization objective in a multi-user, multitask, and multi server scenario. The proposed approach divided the mixed-integer nonlinear programming (MINLP) problem into a resource allocation problem and a task allocation problem. Furthermore, the resource allocation problem was divided into computation resource allocation and communication resource allocation. To deal with these problems, the authors proposed a low-complexity suboptimal matching algorithm for subchannel allocation to maximize task offloading efficiency.

The work developed in [22] addressed the joint allocation of spectrum, computation, and storage resources in a multi-access edge computing (MEC) based vehicular network. Two typical MEC architectures were considered, and multidimensional resource optimization problems were formulated. The authors of the work utilized the optimization problems with the aim of maximizing the number of tasks offloaded while meeting quality of service (QoS) requirements, considering the limited quantities of available spectrum, computation, and storage resources. To achieve the ideal spectrum allocation between base stations and the optimal allocation of spectrum, computation, and storage among vehicles, the authors transformed the optimization problems into a Deep Reinforcement Learning problem and proposed an algorithm based on deep deterministic policy gradients to solve them.

While the previously presented work focused on offloading through MEC servers, our proposed work focuses on data offloading through RSUs, transferring data traffic from the
4G/5G cellular network to the IEEE 802.11p vehicular network with the assistance of MEC servers. Unlike the distributed computing approach used in traditional Vehicular Ad Hoc Network (VANET) to find the k-hop V2V path, our proposed work adopts a centralized computing approach, which can be achieved with the help of the MEC server.

In [23], a proposed method for vehicular data offloading, called VVR offloading path selection, based on the destination's retransmission time limit, utilizes a Mobile Edge Computing (MEC) approach instead of the traditional V2I offloading method. The proposed method aims to perform data offloading using RSU X, n hops away, by selecting the most suitable VVR data offloading path. To achieve this, the MEC server receives periodic context reports from vehicles and utilizes detection and reduction (DAS), detection and extension (DAE), and path recovery mechanisms to construct and maintain the VVR data offloading path. The DAS and DAE mechanisms use OA reselection to reconstruct the VVR data offloading path when the originating vehicle enters or exits the signal range of the RSU ahead or behind it. Additionally, the path recovery mechanism is triggered to maintain VVR data offloading if a vehicle in the relay route deviates from the VVR data offloading path. In summary, the proposed method aims to enhance vehicular data offloading by using an MEC-based approach that selects the most suitable VVR data offloading path and maintains offloading using RSU X whenever possible.

The authors of the article [24] proposed a novel method called Delay-Constrained k-hop Limited Utility-based VVR Data Offloading Path Construction Method (DC-KUPC). This method is based on MEC and is used to find the best VVR data offloading path between an originating vehicle and an RSU, considering a time period with a delay constraint. To implement this method, the MEC server receives a context report from the originating vehicle at time point \( t_r \) and then calculates all possible VVR data offloading paths between the originating vehicle and RSU Y within a time period of \( t_r + T \). \( T \) represents the delay-constrained time period, and during this time, the MEC server searches for all candidate VVR data offloading paths that satisfy the delay constraint.

A utility function is then used to derive the quality of each candidate VVR data offloading path. The utility function takes into account various factors such as path length, bandwidth, and signal intensity. Finally, the DC-KUPC method selects the VVR data offloading path with the highest utility value as the best VVR data offloading path. Compared to the lifespan-based method proposed in [25], which considers only the lifespan of the path without considering the network quality of the path, the proposed DC-KUPC method achieves
better data offloading performance. Simulation results demonstrate that the proposed utility-based method can significantly improve the data offloading performance in VVR systems.

Considering offloading in a multi-RSUs and n-hop environment, three works are presented in the literature. The following three described works do not consider energy consumption for calculating the best route, nor the time it takes for the data to be transmitted. They also do not consider the transmission time of the VVR data offloading path, thus making them unsuitable for real-time solutions. One of these papers presents a method called Predicted K-hop-limited Multi-RSU-considered (PKMR) for vehicle-to-vehicle-to-roadside unit (VVR) data offloading in a multi-access edge computing (MEC) environment. The method utilizes a Software Defined Network (SDN) controller within the MEC server to manage the offloading process. By considering the predicted paths and network conditions of vehicles and roadside units (RSUs), the PKMR method selects the most suitable VVR data offloading path. The performance evaluation shows that PKMR outperforms traditional self-offloading methods. The proposed method addresses challenges related to multi-RSU deployment, RSU signal overlap, and data offloading [26]. But it does not consider energy consumption for calculating the best route, nor the time it takes for the data to be transmitted, thus making it unsuitable for real-time solutions.

In the work presented in [27], the authors propose a multi-user and multi-RSU system architecture based on the Internet of Vehicles (IoV) using SDN. In order to reduce the offloading delay in IoV, a joint approach is proposed to optimize the offloading rate, offloading decisions, and resource allocation. The solution proposes the use of RSUs for computing vehicular network activities in order to balance the utilization of computational resources between the vehicular network and RSUs. Although the work proposes the use of multi-RSUs, it does not address the case when the signals from the RSUs overlap. It also does not handle the reselection of a new path if there is a disconnection of vehicles that are part of the offloading path.

Some of the core concerns in the existing methods are the following:

- some papers work with the traditional V2I scenario, which means offloading considering only one hop;
- some of the metaheuristic methods can be implemented in making the resource utilization to maximum levels and can also be distributed to other nodes [28];
- some of the previously presented work focused on offloading just through MEC servers;
● alternative ways in exploring and defining the critical areas are reduced as rectangular regions. They are not applicable in some of the scenarios. Also, an extended approach can be made in finding other applications for enhancing the content viability and in reducing the backhaul traffic [7];
● the presented works do not take into account energy consumption as well as the time it takes for the data to be transmitted, thus making it impractical for real-time solutions.

Proposed Methodology

This section presents the complete work methodology. The wireless vehicular communication uses RSU’s. These RSU’s are efficient in making short range communications which are operated in a short spectrum range. The proposed method uses the VVR-RSU signalling protocol. In the initial levels, the system model consists of VVR, which is the path chosen. It is used in the offloading of the destination vehicle. This is done using the proposed CN-MHMR, with the Vehicle to Vehicle - RSU. This combination is known to be RSU-VVR. The data is transferred from one node to another that receives the packet via the efficient energy routes. These data packets are transferred from the node (vehicle) using the nearest RSU. This is done for finding the efficient route for the effective data transfer. Using the energy efficient routes results in energy efficient data transfer. Some of the parameters analysed comprises the bandwidth, the packet delivery ratio, the energy consumption and the throughput.

The diagrammatic representation of the proposed method is given in Figure 1. It can be seen in the diagram that the first step in the CN-MHMR module, the first thing to do is the agent's initialization. When a node receives a data packet, the best route is calculated based on the external fitness evaluation of the RSU signal, energy estimation and the best link quality between vehicles, calculated using complex network metrics. The retransmission probability is calculated for each data packet received, forming a loop until the broadcast decision is carried on. When the packet is broadcasted, it is discarded by the CN-MHMR. The performance analysis is made over all the collected data: energy consumption, bandwidth, throughput, delay and packet delivery ratio are some of the possible metrics to be presented. All the modules and methods will be detailed explained in the next sections.
3.1 Proposed Method CN-MHMR

The proposed approach comprises four stages as outlined below: (a) Initialization Phase; In this stage the vehicle Vs utilizes the network while the MEC server endeavors to find a V2V2I VANET offloading route, for Vs. (b) Shrinking Phase; During this phase vehicle Vs moves towards an RSU that provides signal coverage gradually reducing the length of the V2V2I VANET offloading path. This reduction is achieved by decreasing the number of hops in the V2V2I path. (c) Self offloading Phase; At this point vehicle Vs is within range of an RSUs signal coverage. Can independently perform offloading without relying on vehicles. (d) Extending Phase; Throughout this phase vehicle Vs moves from the RSUs signal coverage area resulting in an increase in the number of hops required for V2V2I communication. In phases 2 and 4 there may be instances where it becomes necessary to reconstruct the path. If
such a situation arises the algorithm returns to phase 1 to recalculate routes and establish links, between network nodes.

3.1.1 The initialization phase

Initially, the vehicle Vs uses the 4G/5G cellular network to communicate with its peer Vp on the infrastructure Internet side. When the MEC server receives the periodically reported context from vehicle Vs at time point Tc, it is triggered to determine if there are one or more V2V2I offloading paths for the vehicle Vs. If the MEC server finds a V2V2I offloading path for Vs, it calculates all potential V2V2I paths that may exist during the interval [Tc, Tc + t] and selects the best one as the V2V2I offloading path, generated at time point T0, where To is within the interval [Tc, Tc + t], for Vs. Subsequently, the MEC server sends messages to the constituent vehicles of the corresponding V2V2I offloading path to enable the V2V2I VANET offloading session for Vs at time point T0.

The delay-constrained time length t is set to be smaller than or equal to the corresponding vehicle's periodically reported context time period because the MEC server can only receive the next reported context after one periodic reporting time period. During the offloading session, all constituent vehicles of the V2V2I offloading path synchronously report their contexts to the MEC server, which can be achieved by aligning the time with GPS time. After receiving the reported contexts from the constituent vehicles of the V2V2I offloading path, the MEC server calculates the time for each V2V link and the V2I link, which represents the offloading agent's duration inside RSU's signal coverage, to update the remaining offloading time of the corresponding V2V2I offloading path.

The initial step involves identifying the start time points and end time points for all links. It is based on the location speed of every node pair (p,q) in the environment (NodeSet), the geo-distance, signal range of the on-board unit and fitness function for energy. To achieve this, Procedure 1 in Figure 2 is executed, to derive the start time point and end time point of each link, which was proposed in [26]. Consider the position and speed of each pair of vehicles p and q, where both p and q are part of the NodeSet at time point t0. These can be represented as the coordinates [Posx(p),Posy(p)] and [Posx(q),Posy(q)], and the velocities [Velx(p),Vely(p)] and [Velx(q),Vely(q)], which can be communicated in a range R of 300m (equal to IEEE 802.11p OBU).
Figure 2

Procedure Find All of the Links’ Connected Time Intervals

<table>
<thead>
<tr>
<th>Procedure 1: Find All of the Links’ Connected Time Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: for each Link ((p, q)) do |</td>
</tr>
</tbody>
</table>
| 2: \[
\left( p \cdot x(p) - p \cdot x(q) + t \cdot (V_x(p) - V_x(q)) \right)^2 + \]
| \[
\left( p \cdot y(p) - p \cdot y(q) + t \cdot (V_y(p) - V_y(q)) \right)^2 - R \cdot R = 0 \]  |
| 3: End for \|

If there are no solutions, to the equation used in Procedure 1 it means that the shortest distance between object \(p\) and object \(q\) is greater than \(R\). Consequently Link \((p, q)\) is considered invalid and removed from the analysis. If there is one solution it indicates that Link \((p, q)\) breaks immediately and needs to be removed. However if there are two solutions it implies that Link \((p, q)\) exists for a time interval where one solution represents the starting time point and the other solution represents the ending time point of Link \((p,q)\). In cases where an infinite number of solutions exist it suggests that Link \((p,q)\) can persist indefinitely. This means that objects \(p\) and \(q\) have the driving speed and direction while their initial distance is not greater than \(R\).

Once we have identified all start time points and end time points for each link we can determine the suitable VVR data offloading path. For every link, on each path we utilize a success probability function (SP).

\[
SP = Ql \ast Ff \ast Cp \quad \text{(1)}
\]

Each of the components of the formula will be specified below. The quality function takes into account several factors to determine the quality of a V2V2I offloading path. These considerations are as follows: (i) A longer lifetime of the V2V2I path leads to a higher utility value, indicating its desirability, (ii) If there are more vehicles within the signal coverage of a constituent vehicle, it may result in potential transmission collisions, leading to a lower utility value due to higher backoff values required for channel access, (iii) The total number of vehicles within the signal coverage of each constituent vehicle influences the path's utility value, indicating that a more congested road results in a lower utility value. A quality function that can derive the VVR data offloading path’s quality is defined as follows, for which the used variables are defined and explained in Table 1. \(Q_l\) is based in [24].
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\[
Q_l = \frac{T^{\text{offloading}}}{\alpha (2^{\left\lfloor \log_2 N^{\text{max}} \right\rfloor} + N^{\text{max}}) + (1 - \alpha) N^{\text{total}}} \cdot \frac{1}{\sqrt{\sum_{i=1}^{n} i}}
\]

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T^{\text{offloading}})</td>
<td>The lifetime of the V2V2I offloading path, which is the minimum link's connected time of the constituent links in the V2V2I offloading path.</td>
</tr>
<tr>
<td>(N_i)</td>
<td>The number of vehicles that are in the signal coverage of the offloading path's constituent vehicle V.</td>
</tr>
<tr>
<td>(N^{\text{max}})</td>
<td>Max (N1, N2, ..., Nn).</td>
</tr>
<tr>
<td>(N^{\text{total}})</td>
<td>Sum of (N1, N2, ..., Nn).</td>
</tr>
<tr>
<td>(n)</td>
<td>The hop count in the V2V2I offloading path, including the V2I link from the offloading agent to RSU.</td>
</tr>
</tbody>
</table>

The fitness function (Ff), Figure 3, has been designed to evaluate the fitness value of a vehicle's position in a 2D space relative to its counterpart. It takes two parameters as input: energy, which represents the initial energy level of the vehicles and distance, which is a vector containing the distances between the vehicle under consideration and other vehicles in the environment. The function proceeds with calculating three weighted components of the fitness value. Firstly, it calculates the average distance (x1) between the vehicle under consideration and all other vehicles within its sensing range. Secondly, it evaluates x2, which involves comparing the initial energy (energy) to the product of energy and the number of vehicles (Cn) within the sensing range. As the product simplifies to the original energy value, x2 essentially becomes 1. Finally, x3 is obtained as the inverse of the number of vehicles within the sensing range. Using predefined constants alpha1, alpha2, and alpha3, the function combines the three components (weighted accordingly) to generate the final fitness value. These coefficients (alpha1, alpha2, and alpha3) allow us to adjust the importance of each factor in the fitness calculation.
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Figure 3

Algorithm fitnessFunc

<table>
<thead>
<tr>
<th>Algorithm fitnessFunc (energy, distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: alpha1 ← 0.2</td>
</tr>
<tr>
<td>2: alpha2 ← 0.5</td>
</tr>
<tr>
<td>3: alpha3 ← 1 - alpha1 - alpha2</td>
</tr>
<tr>
<td>4: Cn ← sum (distance &lt; Sensing_range)</td>
</tr>
<tr>
<td>5: x1 ← sum (distance) / Cn</td>
</tr>
<tr>
<td>6: x2 ← ((energy * Cn) / Cn) / energy</td>
</tr>
<tr>
<td>7: x3 ← 1 / Cn</td>
</tr>
<tr>
<td>8: fitness_val ← (alpha1 * x1) + (alpha2 * x2) + (alpha3 * x3)</td>
</tr>
<tr>
<td>9: end</td>
</tr>
</tbody>
</table>

The efficiency of a link in performing transmission is determined by a probability function that considers factors such as vertex degree, topological overlap, and edge persistence. This function calculates the transmission success probability (Cp), which is then compared to a threshold value derived from an exponentially weighted moving average. If Cp exceeds the threshold, the link is penalized and may be ranked lower. The selection of components for calculating the retransmission probability is based on the significance of a specific vehicle in the network's packet retransmission process. The following complex network metrics are used [29]:

- **vertex degree**: Vertices with a higher degree are more active in the network and can serve as channels for information exchange;
- **topological overlap**: Depicts the tendency for vertices to have shared neighbors. Therefore, the fewer shared neighbors, the higher the possibility of reaching a larger number of vehicles;
- **edge persistence**: Defines the number of times two vertices encounter each other within the same time window. Vehicles that encounter each other in the same time window have a higher probability of successful information exchange.

The value of p is calculated by the product of the probability associated with the Vertex Degree (pGV), the probability associated with the Topological Overlap (pST) and the probability associated with Edge Persistence (pPA), formulated by the Equation 3:

\[ Cp = pGV \times pST \times pPA \]  

(3)

To compute the pGV for a particular vehicle, it requires information about the vertex degree of all its neighboring vehicles, which is kept and updated in its neighbor table. The
vehicle then calculates the ratio between its own vertex degree ($g_V$) and the sum of the vertex degrees of its neighbors ($g_{VV}$).

$$p_{GV} = \frac{g_V}{g_{VV}}$$  \hspace{1cm} (4)

While disseminating data, it is preferable to choose vehicles with the fewest common neighbors. The calculation of $p_{ST}$ is determined by subtracting one from the quotient of the number of common neighbors ($n_{VC}$) divided by the sum of the transmitter's neighbors ($n_{VT}$) and the receiver's neighbors ($n_{VR}$).

$$p_{ST} = 1 - \frac{n_{VC}}{n_{VT} + n_{VR}}$$  \hspace{1cm} (5)

The transmitting vehicle takes into account the two seconds leading up to the receiver selection in order to compute the $p_{PA}$ value. If the link was consistently active during those two seconds, $p_{PA}$ is assigned a value of 1. If it was active only in the last second, it receives a value of 0.5. If there was no link in the last second, it is assigned a value of 0, preventing the vehicle from being selected as a receiver. After calculating $C_p$, it is essential to verify if the value surpasses the threshold. If it exceeds the threshold, it undergoes a 50% penalty, and the penalized link is moved to the last position.

The threshold calculation is based on the methodology employed by the E-probT protocol outlined in [30]. The initial threshold value, denoted as $avgThr$, is derived by computing the average $C_p$ for the three vehicles farthest from the transmitter. To refine this value, it undergoes a weighted exponential moving process that takes into account both past and current values for computing new thresholds. This process aims to mitigate potential discrepancies and errors in the ongoing estimation. Similar to TCP's timeout mechanism, it involves a smoothing of the values curve. Using $avgThr$, the estimated threshold value, referred to as $estThr$, is determined as shown in Equation 6, which represents the calculation for the estimated threshold.

$$estThr = (1 - \beta) \ast estThr + \beta \ast avgThr$$  \hspace{1cm} (6)
The value of the used $\beta$ constant is the same as the work [39][30], recommended value for TCP. Thus, $\beta = 1/8 = 0.125$ [38]. Besides the estimating, it is necessary to calculate the threshold variation, called varThr. This calculation is performed based on the Equation 7.

$$ varThr = (1 - \gamma) \ast varThr + \gamma \ast |avgThr - estThr| $$

(7)

The value of the used $\gamma$ constant is the same as the work [39][30], recommended value for TCP. Thus, $\gamma = 1/4 = 0.250$ [38]. Finally, the final threshold value, called endThr, is calculated by the sum of its estimated value (estThr) and the variance (varThr) value. Equation 8 shows the calculation for the final threshold value.

$$ endThr = estThr + varTh $$

(8)

With the defined probability of success function, the candidate paths for offloading can be determined. The InitContenderSet, Figure 4, algorithm aims to initialize the set of candidate paths for finding the best path from Vroot to other nodes within a node set (NodeSet) and a time point set (TimeSet). Firstly, the set of candidate paths (ContenderSet) is initialized as empty. Then, the algorithm iterates through each node $v$ in the NodeSet and each time point $t$ in the TimeSet. During the iteration, the algorithm checks if there is an existing link between Vroot and node $v$ that is active at time point $t$. If such a link exists, a new candidate path is created, starting at Vroot and ending at $v$, at time point $t$. The new candidate path is then assigned with relevant information, including the start node, end node, postponed time, lifetime, quality of the path calculated using a specific function, and hop count, which is set as 1 since it is a one-hop path from Vroot to $v$. This candidate path is added to the set of candidate paths (ContenderSet) for further consideration. After completing the iterations through the nodes and time points, the algorithm returns the ContenderSet containing all possible paths from Vroot to nodes in the NodeSet that are active at their respective time points. This set will be used in subsequent processes to determine the best path from Vroot to the final destination node or Roadside Unit (RSU).

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São José dos Pinhais, Paraná, Brasil.
Algorithm InitContenderSet

<table>
<thead>
<tr>
<th>Algorithm InitContenderSet(Vroot, NodeSet, TimeSet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: ContenderSet ← ∅</td>
</tr>
<tr>
<td>2: linksToVroot ← Links from Vroot to NodeSet</td>
</tr>
<tr>
<td>3: for each v in NodeSet do</td>
</tr>
<tr>
<td>4: for each t in TimeSet do</td>
</tr>
<tr>
<td>5: for each link (p, q) in linksToVroot do</td>
</tr>
<tr>
<td>6: if tstart(link) ≤ t and tend(link) &gt; t then</td>
</tr>
<tr>
<td>7: NewContenderPath ← Create new path from Vroot to v</td>
</tr>
<tr>
<td>starting at t</td>
</tr>
<tr>
<td>8: End(NewContenderPath) ← v</td>
</tr>
<tr>
<td>9: PostponedTime(NewContenderPath) ← t</td>
</tr>
<tr>
<td>10: Lifetime(NewContenderPath) ← tend(link) - t</td>
</tr>
<tr>
<td>11: Quality(NewContenderPath) ← ComputeQuality(NewContenderPath)</td>
</tr>
<tr>
<td>12: HopCount(NewContenderPath) ← 1</td>
</tr>
<tr>
<td>13: add NewContenderPath to ContenderSet</td>
</tr>
<tr>
<td>14: end if</td>
</tr>
<tr>
<td>15: end for</td>
</tr>
<tr>
<td>16: end for</td>
</tr>
<tr>
<td>17: end for</td>
</tr>
<tr>
<td>18: return ContenderSet</td>
</tr>
</tbody>
</table>

Algorithm CBOP (Constrained Best-Offloading Path), Figure 5, is designed to find the best data offloading path in a V2V2I (Vehicle-to-Vehicle-to-Infrastructure) vehicular network. The goal is to identify the path that offers the best communication quality while considering the delay constraint imposed by the system. The algorithm begins by initializing a set of candidate paths (ContenderSet) using the InitContenderSet function, which creates all possible one-hop paths from the root vehicle Vroot. It then enters a loop (line 2) to iterate over the ContenderSet. Within the loop, the algorithm calculates the quality of all offloading paths in ContenderSet (line 3) and selects the path that has the maximum quality value as Pathmax (lines 4 to 10). If the Pathmax path reaches the RSU (Infrastructure Service Unit), the loop is interrupted as the best path has been found, and there is no need to continue the search. If Pathmax does not reach the RSU, the ContenderSet is updated to contain only promising paths to continue the search (line 15), and the Pathmax path is removed from the set to avoid unnecessary repeated calculations (line 16). The algorithm continues to iterate until there are no more candidate paths in the ContenderSet. It then returns the Pathmax path, which is considered the best data offloading path within the constraints of delay and quality.
An approach for offloading with multi-hop considerations in an RSU signal overlay setting

3.1.2 The shrinking phase

The main goal is to maintain the V2V2I offloading path for as long as possible. When the MEC server receives the periodically reported context from the offloading agent at the current time point $T_c$, it knows that the offloading agent will be out of the RSU's signal coverage when its next periodically reported context is received, indicating that it is leaving the RSU's signal coverage. To address this, the shrinking algorithm is triggered to find a new offloading agent and update the V2V2I offloading path. The MEC server selects the updated path from all the potential paths that may exist during the interval $[T_c, T_c + t]$. The sub-path of the V2V2I offloading path that lies outside the RSU's signal coverage is referred to as sub-pathout-RSU.

To ensure that the delay-constrained time length $t$ does not exceed the lifetime of sub-pathout-RSU, the delay constraint is defined to be smaller than or equal to the lifetime of sub-pathout-RSU. If a new offloading agent and/or an updated V2V2I offloading path cannot be found, the MEC server will inform vehicle $V_s$ to switch back to the cellular network, and the offloading session will be terminated. However, if vehicle $V_s$ remains within the RSU's signal coverage, indicating that the offloading path is still intact, the shrinking phase is concluded, and vehicle $V_s$ can continue with the offloading on its own.
3.1.3 The self-offloading phase

When vehicle Vs is within the signal coverage of the RSU, it can directly communicate with its Vp through the RSU. During this phase, the MEC server continuously calculates the time duration that vehicle Vs stays within the RSU’s signal coverage, based on the periodically reported context from Vs. The MEC server receives the context from Vs at a certain time point Tc, and it knows that vehicle Vs will leave the RSU’s coverage when its next context is received, indicating that vehicle Vs is moving out of the RSU’s signal coverage. This transition triggers the start of the extending phase.

3.1.4 The extending phase

When the source vehicle Vs or the offloading agent of the extending phase moves out of the RSU’s signal coverage, the extending algorithm is activated. At the current time point Tc, the MEC server receives the periodically reported context of the offloading agent, and it predicts that the source vehicle or the offloading agent will leave the RSU’s signal coverage upon receiving its next context. This event triggers the extending algorithm, which aims to find a new offloading agent and an updated V2V2I offloading path. The MEC server evaluates all potential candidates that may be available during the interval [Tc, Tc + t]. The current V2V2I offloading path from vehicle Vs to the offloading agent, which is inside the RSU’s signal coverage but is leaving it, is referred to as sub-pathc-offloading. To ensure that the delay-constrained time length t is reasonable and doesn’t exceed the lifetime of sub-pathc-offloading, t is defined to be smaller than or equal to the lifetime of sub-pathc-offloading. If the MEC server cannot find a new offloading agent and/or an updated V2V2I offloading path, it will notify vehicle Vs to switch back to the cellular network, and the offloading session will be terminated.

3.1.5 Reconstruct the offloading path

When a V2V2I offloading path experiences an unexpected breakage, the path recovery algorithm is triggered to restore the connection. Let’s consider a sub-path Vb – Vy –Va within the V2V2I offloading path for vehicle Vs. If Vb is unable to transmit data to Va, for example, because Vy has left the road, resulting in the breakage of the V2V2I offloading path, we denote this event as the broken time point Tc. The path recovery algorithm attempts to find a new...
vehicle Vx that can repair the V2V2I offloading path, or it looks for an opportunity for Vb to reconnect with Va within the interval of \([T_c, T_c + t]\). Here, sub-patha represents the current offloading sub-path from Vs to Va, and sub-pathb-OA represents the current offloading sub-path from Vb to the offloading agent. To ensure that the delay-constrained time length \(t\) is reasonable and doesn't exceed the lifetimes of sub-patha or sub-pathb-OA, \(t\) is defined to be smaller than or equal to the minimum lifetime between sub-patha and sub-pathb-OA. If the path recovery algorithm fails to repair the V2V2I offloading path, the MEC server will inform vehicle Vs to switch back to the cellular network, and the V2V2I offloading session will be terminated.

**Results and Discussion**

The proposed method using the VVR - with the CN-MHMR algorithm is used in finding the energy efficient routes for effective data transfer from one node to the other. The complete results which were obtained after the placement of the projected process is presented in the respective section.

**4.1 Simulation Results**

This subsection contains the system model which is deployed in the particular study, the graph depicting the routing path and the method of selecting the cluster head for the effective data transfer.
Figure 6

System model for proposed methodology

Figure 7

Cluster head selection by CN-MHMR
Figures 6 and 7 depict the system model, and the cluster head selection which is energy efficient making less discrete packets and increased rates of broadcast packets. The system model represented is deployed for the proposed study used in finding the effective route for node transfer. Whereas cluster heads selection is found using the proposed CN-MHMR model for effective VVR (Vehicle-to-Vehicle-to-Roadside) multi-hop path to perform offloading. Figure 8 represents the routing path found using the proposed algorithm for the effective data transfer from one node to the other. This is used in making easier and effective means of communication facilitating the effective node transfer. Only after the effective selection of the cluster head the energy effective route is selected and is optimised for effective node transfer from the base station to the destination node. The groups inside each of the clusters represent the individual groups, which are considered as one single group. These clusters are instructed in following one effective route of the node transfer.

The departure time intervals for vehicles vary depending on the density of vehicles. In high-density situations, the departure time period is 0.8 seconds, in medium-density situations it is 1.25 seconds, and in low-density situations, it is 2 seconds. Each vehicle starts from a fixed position and exhibits random driving behaviors. Vehicles have the option to drive away using the available road intersections. When a vehicle is on the road, it sends a context report to the MEC server at regular intervals. In normal situations, the report is transmitted every 2 seconds. However, if the vehicle is part of a VVR (Vehicle-to-Vehicle-to-Roadside) data offloading path, the report is transmitted every 1 second. The data flow between an
infrastructure entity on the roadside and the source vehicle can be established through either an RSU (Roadside Unit) using an IEEE 802.11p network or a BS (Base Station) using an LTE cellular network. The data is then transmitted to the source vehicle. Table 2 provides an overview of the simulation environment parameters and their respective values.

Table 2
Parameters used in the simulation environment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation time length</td>
<td>300s</td>
</tr>
<tr>
<td>Vehicle´s departure time period</td>
<td>0.8s/1.25s/2s</td>
</tr>
<tr>
<td></td>
<td>(high/medium/low)</td>
</tr>
<tr>
<td>Vehicle´s velocity limit</td>
<td>60km/h</td>
</tr>
<tr>
<td>Context reporting period</td>
<td>1s/2s</td>
</tr>
<tr>
<td>RSU signal range</td>
<td>300m</td>
</tr>
</tbody>
</table>

4.2 Performance Analysis

This subsection is used in representing the overall performance exhibited by the proposed method, for effective node transfer from one node to the other and from the base node to the destination node. The complete section relies on depicting the fraction of data offloading levels at different hop levels for the routing in wireless communications.

Four construction strategies for the vehicular network's data offloading path are evaluated in this study. The first one is the proposed method, a k-hop-limited multi-RSU VVR data offloading approach considering quality of service, energy consumption, and time-extended prediction mechanism. The second method has the same characteristics but does not consider energy consumption for route calculation or delivery probability. The third method is a k-hop-limited multi-RSU VVR data offloading approach considering quality of service, without using the time-extended prediction mechanism. The fourth comparison method does not allow for RSU handoff if the link with the RSU is lost.

About the four strategies, four performance metrics were evaluated: (I) Data loss rate: This metric quantifies the proportion of lost data in the VVR data offloading path, divided by the total amount of data transmitted through RSUs. (II) Data offloading fraction: This metric represents the proportion of offloaded data that were directed through RSUs, divided by the total amount of data directed through both the BS and RSUs. (III) Successful data offloading fraction: This metric indicates the proportion of data that were successfully received by the source vehicle through the VVR data offloading path, divided by the total amount of data transmitted through both the BS and RSUs. (IV) Number of data offloading sessions: This
An approach for offloading with multi-hop considerations in an RSU signal overlay setting

metric represents the average number of data offloading sessions that existed during the simulation.

**Figure 9**
*Data loss rate at 10 hop*

![Data Loss Rate 10-hop](image)

**Figure 10**
*Data loss rate at 8 hop*

![Data Loss Rate 8-hop](image)

The graphics, in Figures 9, 10, 11 and 12 illustrate how the rate of data loss varies with numbers of hops. Several factors contribute to the data loss rate. Firstly when there are vehicles on the road the data loss rate tends to increase. This happens because higher vehicle density leads to data transmission between vehicles, which can result in collisions if the data is sent through the VVR data offloading path. This collision effect contributes to a data loss rate. Secondly as the number of hops increases so does the data loss rate. This is because a
longer VVR data offloading path means that the transmitted data needs to pass through VV links making it more vulnerable to losses.

Figure 11
*Data loss rate at 4 hop*

![Data Loss Rate 4-hop](image)

Figure 12
*Data loss rate at 2 hop*

![Data Loss Rate 2-hop](image)

Thirdly, the data loss rate in methods 1 and 2 is slightly lower than in method 3. This means that methods adopting the time-extended prediction mechanism in conjunction with energy optimization have a lower data loss rate. This is because the time-extended prediction mechanism helps the MEC server find more candidate paths. Additionally, a candidate path that consumes less energy requires less effort for package delivery, increasing the probability of successful delivery. Therefore, the selected VVR data offloading path can provide better quality of service (QoS), resulting in a lower data loss rate. Lastly, the data loss rate in methods
1 and 2 is slightly lower than in method 3. This means that methods allowing the OA to perform RSU handoff in regions with overlapping RSU signals, i.e., in environments with multiple RSUs, have a lower data loss rate.

**Figure 13**

*Data offloading fraction at 2 hop*

**Figure 14**

*Data offloading fraction at 4 hop*
Figure 15

Data offloading fraction at 8 hop

![Data Offloading Level 8-hop](image)

Figure 16

Data offloading fraction 10 hop

![Data Offloading Level 10-hop](image)

The Figures 13, 14, 15 and 16 graphics deliberate the overall data fraction of the proposed model in the wireless sensor, for a data transfer from one node to the other. The data offloading fraction is the amount of offloading data that was directed through RSUs divided by the amount of data that was directed through both the BS and RSUs. There are four factors that affect the data offloading fraction. Firstly, a higher vehicle density leads to an increased data offloading fraction. This is because a VVR data offloading path is more likely to be established in situations with a higher vehicle density. Secondly, the data offloading fraction is higher when the system has a larger hop count limit. This is because a larger hop count limit allows the source vehicle to initiate data offloading earlier, enabling the establishment of a
data offloading session at an earlier stage. As a result, the total time for offloading data traffic is longer, leading to a higher data offloading fraction.

Thirdly, the data offloading fraction from method 1 and 2, which employs the time-extended prediction mechanism, is always higher than other methods. This relationship is due to the fact that the time-extended prediction mechanism offers two advantages. The first advantage is the potential utilization of VVR data offloading paths with shorter lifetimes. Another advantage of the time-extended prediction mechanism is the ability to initiate a data offloading path at an earlier time point. This advantage arises from the detection of potential VVR data offloading paths that may not exist at the time when the MEC server receives the source vehicle's periodic context report but will become available in the future, specifically between two consecutive time points of context reports.

The fourth factor that affects the data offloading fraction is the deployment of multiple RSUs and RSU handoff. In methods 1 and 2, where both the OA (Offloading Agent) and the source vehicle can utilize RSU handoff in regions where multiple RSUs have overlapping signals, the data offloading fraction in a multi-RSU environment is higher compared to other methods, where the OA does not perform RSU handoff. This relationship occurs because if the MEC server cannot find an alternative VVR data offloading path using the OA reselection scheme, the method that incorporates RSU handoff can maintain the VVR data offloading session by transitioning to subsequent RSUs along the original path. As a result, enabling both the OA and the source vehicle to perform RSU handoff extends the duration of the VVR data offloading session, resulting in a higher data offloading fraction.

Figure 17

Successful Data offloading levels at 2 hop levels
Figure 18
Successful Data offloading levels at 4 hop levels

Figure 19
Data offloading levels at 8 hop levels

Figure 20
Data offloading levels at 10 hop levels
The same successful data of lading levels using different density of the node hop are depicted in the Figures 17, 18, 19 and 20 graphics. The successful data offloading fraction is influenced by both the data offloading fraction and the data loss rate. Observing the evaluation results, can be seen that the successful data offloading fraction is proportional to the vehicle density. This relationship occurs because higher vehicle density leads to a higher data offloading fraction, outweighing the impact of the increased data loss rate. Additionally, increasing the hop count limit in each vehicle density situation increases the successful data offloading fraction. This is due to the fact that the effects of enabling the OA to perform RSU handoff in a multiple-RSU environment and utilizing the time-extended prediction mechanism have a more significant impact than the data loss rate. As a result, the successful data offloading fraction is greater in high vehicle density situations compared to low vehicle density situations.

**Figure 21**

*Number of Session at 2 hop*
An approach for offloading with multi-hop considerations in an RSU signal overlay setting

Figure 22
Number of Session at 4 hop

Figure 23
Number of Session at 8 hop

Figure 24
Number of Session at 10 hop
The evaluation results depicted in Figures 21, 22, 23 and 24 illustrate that the number of data offloading sessions varies based on both the hop count limit and vehicle density. When considering a hop count limit (2 hop 4 hop limited) it is observed that the medium vehicle density scenario exhibits the highest number of sessions compared to situations, with low and high vehicle densities. This can be attributed to the opportunities for the MEC server to find VVR data offloading paths in scenarios with medium vehicle density resulting in paths with shorter lifetimes and consequently leading to a higher number of sessions. On the hand when dealing with a hop count limit (8 hop and 10 hop limited) the number of sessions shows an inverse relationship with vehicle density. As vehicle density increases there is a decrease in the number of data offloading sessions. This can be explained by considering that in scenarios with a hop count limit there are possibilities, for selecting longer lifetime VVR data offloading paths instead of shorter ones. Consequently this prolongs the lifespan of a session while reducing the overall number of sessions.

To summarize when we raise the hop count limit from 2, to 4 it leads to a number of offloading sessions in scenarios with a hop count limit. On the hand increasing the hop count limit from 8 to 10 results in a decrease in sessions for situations, with a hop count limit.

**Conclusion**

In a multi-RSU and multi-vehicle environment, it is necessary to develop solutions that consider all possibilities to reduce packet loss and network data traffic. CN-MHMR has demonstrated that utilizing parameters related to link quality between vehicles and the energy factor as inputs to select the best data traffic path should be embraced by existing and future solutions. Until this present work, these metrics were not taken into consideration. Compared to solutions presented in the literature up to this point, CN-MHMR decreased the packet loss rate, increased the success in offloading, and maintained a stable number of sessions, just like previous solutions. When analyzed in comparison with well-established generic solutions from the literature, CN-MHMR showed improvements in all the metrics analyzed. Future work may include testing with new mobility models, as well as the adoption of other wireless communication technologies, such as 5G cellular networks. Additionally, new methods for calculating the probability of successful delivery could be proposed, advancing the fitness function, link quality, and link efficiency.
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