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An Enhanced Algorithm of Improved Response Time of ITS-G5 Protocol

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***Abstract*—This research article proposes an algorithm for improving the ITS-G5 protocol, which addresses the issue of response time. The algorithm includes the integration of Dijkstra's algorithm to prioritize shorter paths for message transmission, resulting in reduced delays. The initial algorithm for the ITS-G5 protocol is presented, followed by the modified algorithm that incorporates Dijkstra's algorithm. The modified algorithm utilizes a node-based approach and implements Dijkstra's algorithm to find the shortest path between two nodes. The algorithm is evaluated in a scenario involving 20 vehicles, where each vehicle has its own message. The results show improved communication efficiency and reduced response time compared to the original ITS-G5 protocol.**

Keywords*—ITS-G5 (Intelligent Transport Systems); V2V (Vehicle-to-Vehicle); V2I (Vehicle-to-Infrastructure); V2X (Vehicle-to-everything); autonomous vehicle

I. INTRODUCTION

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, also known as vehicle-to-everything (V2X), involve wireless technology with the aim of facilitating data exchanges between an automobile and its environment. In recent times, two primary standards for vehicular communication have emerged, utilizing the specially allocated 5.9GHz unlicensed frequency band. On one hand, there is the Dedicated Short-Range Communications (DSRC) protocol, developed in the United States [1]. On the other hand, there is the Intelligent Transportation System (ITS-G5) protocol, created by the European Telecommunications Standards Institute (ETSI).

These standards are built upon the IEEE 802.11p access layer, which was specifically designed for communication within vehicular networks, [2]. Additionally, the connectivity layer specified in the European "Delegated Act" is built upon the IEEE 802.11p standard for vehicular networks [3]. The objective of intelligent transportation systems (ITS) is to enhance traffic security, effectiveness, and the convenience of automobile occupants by utilizing different detectors, gadgets, physical structures, and communication technologies.

Collaborative-ITS systems facilitate direct links between automobiles V2V communication or between automobiles and infrastructure (V2I or I2V communications). These links are supported by onboard units, services, and specialized devices that employ specific interfaces between automobiles, susceptible road users (VRUs), and roadside units (RSUs) [4]. To summarize, the Intelligent Transportation System (ITS) serves as a catalyst for enhanced road safety and the advancement of autonomous vehicle technologies.

Additionally, it aims to improve traffic efficiency by promoting smoother and more efficient flow of vehicles. The scope of ITS encompasses various applications, including driver convenience, public transportation, and commercial transportation of goods.

Within this framework [5], the concept of vehicle-to-everything (V2X) communication refers to real-time communication within the transportation domain.

This communication paradigm facilitates seamless interactions and data exchange between vehicles, infrastructure, pedestrians, and other entities, enabling the realization of innovative and interconnected transportation solutions.

ITS-G5 quickly established itself as a catalyst, spurring the rapid development of state-of-the-art applications in the field of traffic efficiency and safety [6]. Its implementation as a reliable communication framework for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) interactions paved the way for significant advancements and breakthroughs in this domain. ITS-G5 is an access technology developed by ETSI specifically designed to enable communication between vehicles, infrastructure, and various ITS services.

This communication is facilitated through the encapsulation of safety and non-safety applications into Cooperative Awareness Message (CAM) [7] and Decentralized Environmental Notifications Message (DENM).

These messages are then encapsulated into Geo-networking messages and transmitted using the Basic Transport Protocol (BTP) at the access layer, while being regulated by the Decentralized Congestion Control (DCC) mechanism.

Like several protocols, the ITS-G5 protocol algorithm has drawbacks such as interoperability, spectrum availability, and deployment challenges. However, one of the major concerns is the response time, which significantly affects the efficiency of communication between vehicles.

That is why the main objective of this paper is to propose an improved algorithm for the ITS-G5 protocol, aiming to reduce and optimize the response time by incorporating the Dijkstra algorithm, by utilizing the Dijkstra algorithm, the ITS-G5 protocol can give priority to the most optimal routes for message transmission, thereby reducing time lags and enhancing the overall effectiveness of communication. This empowers vehicles to make quicker and well-informed judgments grounded on real-time information, amplifying their capacity to promptly react to significant occurrences or potential dangers on the road.

II. RELATED WORK

Multiple investigations, primarily through simulation-based studies, have been carried out to examine the performance of ITS-G5 protocols. However, the performance of the ITS-G5 protocol falls short, particularly in the context of platooning. A comparison of results with and without data traffic from regular vehicles reveals that greater reliability is achieved when there is no additional data traffic from regular vehicles [8], and when the Cooperative Control Channel (CCH) is exclusively dedicated to interpolation communication. This noteworthy enhancement in performance can be attributed to a significant reduction in packet collisions.

BRISA, a prominent Portuguese highway and mobility services provider, engaged in a collaborative effort with the Institute of Telecommunications (IT) [9] to address the complex challenges inherent in intelligent vehicular networks (IVNs) these challenges posed by latency and throughput.

The primary focus of their joint endeavor was to tackle the issues of latency and throughput, particularly within the context of the emerging IEEE 802.11p standard. These challenges arise due to the dynamic nature of vehicular networks, where variable vehicle speeds disrupt connectivity and necessitate frequent recalculations for effective node coordination. In response, BRISA and IT embarked on a series of research initiatives designed to enhance communication performance within the demanding conditions of IVNs. Their collaborative efforts encompassed the development of novel technologies, the establishment of real-world experimentation platforms, rigorous testing and validation processes, and the formulation of advanced communication protocols. Through these concerted efforts, the goal was to optimize latency, throughput, and communication reliability, thereby contributing to the advancement of safer, more efficient intelligent transportation systems.

Scientific research has provided evidence that the response time of the ITS-G5 protocol is indeed a significant drawback. Numerous studies have consistently shown that the protocol's prolonged response time can result in communication delays between vehicles and infrastructure, which in turn can have adverse effects on the overall performance of the system. These research findings highlight the critical need for enhancing the response time of the ITS-G5 protocol to ensure optimal communication efficiency, particularly in applications related to autonomous driving and road safety.

According to Mayssa Dardouret al. [10] an arrangement has been proposed to accomplish swift response durations and concentrates on the distribution of Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM) for the enhancement of road user safety. With the intention of averting mishaps, an algorithm for CAM and DENM distribution has been formulated, ensuring prompt notifications in the event of abrupt vehicle obstruction emergencies. Furthermore, a comprehensive and optimized railway braking plan is introduced to further diminish the chances of accidents. This strategy aims to supply effective and timely deceleration of trains, granting road users ample time to clear the level crossing well in advance and alleviating the potential for potential collisions.

They designed an all-encompassing communication structure that employed IPv4 multicast via 802.11p/ETSI ITS-G5, facilitating effective message dissemination to ensure road user safety in metropolitan settings. Their suggested formula for spreading CAM and DENM guaranteed prompt notifications in case of unforeseen bus obstruction, thus avert mishaps. The outcomes confirmed the efficiency of our framework, demonstrating minimal delay and elevated PRR.

Thomas Otto et al. [11] in his research, suggest a combination including the TSP system (Traffic Signal Priority) which identifies its presence and adapts the timing of the signal to grant a green light for the authorized vehicle, or it lessens the waiting duration, enabling the vehicle to navigate through the intersection more swiftly and securely.

TSP can also facilitate the enhancement of effectiveness and dependability of communal transportation amenities, diminish retort durations for emergency automobiles, and amplify overall traffic stream within city vicinities. GLOSA similarly employs real-time facts regarding the timing of traffic signals, merged with particulars about the pace and location of personal vehicles, to compute the prime pace counsel for every vehicle drawing near their subsequent traffic signal. Broadly speaking, GLOSA aims to curtail fuel consumption and emanations while refining traffic flow and safety via provision of the afforested figures and data to drivers. The combination of the C-ITS provisions TSP and GLOSA will culminate in distinctly noticeable enhancements for the precedence of communal transportation and the resilience of operations. The core conception behind the partnership of infrastructure, traffic signals, and vehicles encompasses the mutual and ceaseless exchange of data, ultimately advancing the caliber of traffic flow and elevating traffic safety.

To reduce this part, it can be deduced that improving the algorithm of the ITS-G5 protocol to reduce response time is of paramount importance for various reasons. A reduced response time enables faster and more efficient communication among vehicles, a critical factor in ensuring road safety. By reducing the time needed for information transmission and reception, the potential risks of accidents are lowered, providing drivers with real-time alerts.

III. THE ITS-G5 COMMUNICATION SYSTEM

In this section, we will present the principle of the ITS-G5 protocol, its advantages, and its greatest challenge. Additionally, we will explain the key components of the ITS-G5 architecture.

A. *ITS-G5 (Intelligent Transport Systems)*

ITS-G5 is a communication protocol specifically tailored to meet the requirements of intelligent transportation systems, encompassing self-driving vehicles among other applications. It provides rapid and efficient data exchange capabilities, accommodating the transmission of substantial volumes of information. Nevertheless, it's worth noting that the deployment of ITS-G5 is subject to certain limitations, and in comparison, to alternative protocols, it may exhibit increased latency periods.

This protocol is built upon the physical (PHY) and medium access control (MAC) layers of the IEEE 802.11p standard, which is now incorporated into IEEE 802.11-2016. The PHY and MAC protocols defined by IEEE 802.11p/ITS-G5 utilize orthogonal frequency division multiplexing (OFDM) and carrier sensing multiple access with collision avoidance (CSMA/CA) [12], respectively. This means that ITS-G5 relies on OFDM for efficient data transmission [9] and CSMA/CA to manage access to the communication medium and avoid collisions betweenconcurrent transmissions.

Additionally, ITS-G5 operates as an asynchronous ad-hoc protocol, allowing for flexible and spontaneous communication between vehicles without the need for centralized coordination.

B. Bandwidth Selection

The bandwidth selection for ITS-G5 (Intelligent Transport Systems) is flexible, allowing for either a 10 MHz or 20 MHz channel bandwidth based on the specific requirements of VANET. The ITS-G5 standard incorporates the Geo-Networking protocol to facilitate efficient vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

These protocols have been standardized by the ETSI. ITS-G5 is built upon the Media Access Control (MAC) and Physical (PHY) layers of IEEE 802.11p, which are integral parts of the IEEE-802.11-2016 standard. Within the ITS-G5 framework, the PHY and MAC layers are precisely defined, adhering to the Open Systems Interconnection (OSI) architecture. This architecture relies on carrier sensing multiple access with collision avoidance (CSMA/CA) [13] and orthogonal frequency division multiplexing (OFDM) techniques. ITS-G5 supports an asynchronous ad hoc protocol, serving as a counterpart to the LTE-V2X synchronous ad hoc protocol, which operates with fixed, predefined time intervals.

C. ITS-G5 (Intelligent Transport Systems) Challenge

Among the drawbacks associated with the ITS-G5 protocol, its incapacity to ensure dependable communication for platooning can be attributed to two key factors:

1) *Substantial update delay (UD)*: The ITS-G5 protocol showcases a significant lag in updating information shared among vehicles within a platoon. This delay can introduce inaccuracies in the data exchanged [14] among vehicles, consequently compromising coordinated actions and potentially unsafe circumstances.

2) *Limited packet delivery rate (PDR)*: The rate at which data packets are effectively delivered through the utilization of ITS-G5 is notably modest. This deficiency in timely and consistent delivery of critical data can impede the real-time communication essential for efficient platooning.

These challenges, stemming from the protocol's structure and inherent attributes, contribute to its limitations in ensuring trustworthy communication within scenarios involving vehicle platooning.

The Response Time or latency in the ITS-G5 protocol may be viewed as a drawback for autonomous vehicles, as minimal delay is vital for numerous applications in autonomous driving. Excessive communication latency can result in erroneous decisions made by the autonomous vehicle, thereby posing safety concerns.

For instance, in a scenario where an autonomous vehicle must react to an emergency situation, such as abrupt braking by another vehicle, substantial communication latency can impede the vehicle from responding promptly enough to avert a collision.

Hence, it is imperative to factor in the latency when choosing a communication protocol for autonomous vehicles.

D. ITS-G5 (Intelligent Transport Systems) Advantages

Among the benefits of the ITS-G5 protocol (Intelligent Transport Systems), the enhancement of road safety stands out [15]. The ITS-G5 protocol is specifically designed to enable wireless communication between vehicles and road infrastructure, as well as between vehicles themselves. This can positively impact road safety in several ways:

1) *Real-time safety warnings*: ITS-G5 allows vehicles to share real-time information about road conditions, obstacles [16], accidents, and other relevant events. Drivers can be promptly informed about potential hazards, assisting them in reacting appropriately and avoiding accidents.

2) *Collision prevention*: Through direct communication between vehicles, ITS-G5 can aid in collision avoidance using the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) technique [17], providing proximity warnings when vehicles are about to dangerously approach one another.

3) *Driving assistance*: The information provided by ITS-G5 can enhance driving assistance systems by offering real-time data about traffic [18], weather conditions, and other factors. This enables drivers to adapt their driving more safely and efficiently.

4) *Traffic management*: Authorities responsible for traffic management can utilize ITS-G5 to gather real-time data about traffic patterns, congestion, and road conditions [19]. This information can assist in adjusting traffic signals and implementing traffic management measures to reduce accident risks.

While the ITS-G5 protocol highlights a multitude of advantages, encompassing real-time safety notifications, collision evasion, and driving support, the integration of the Dijkstra algorithm introduces a compelling avenue to further enrich its capabilities. By assimilating the Dijkstra algorithm, which excels in uncovering the shortest pathways within graphs, the ITS-G5 protocol stands to secure a noteworthy advantage by significantly diminishing response durations. Recognized for its adeptness in route optimization, this algorithm holds the potential to notably expedite decision-making processes, ensuring swifter reactions to potential risks and the selection of optimal routes.

In contrast, the innate strengths of the ITS-G5 protocol, spanning real-time safety alerts, mechanisms for collision prevention, and provisions for driving assistance, establish a robust groundwork for enhanced road encounters, boasting heightened safety and efficiency. Nonetheless, the inclusion of the Dijkstra algorithm ushers in an innovative dimension that capitalizes on its capability to swiftly compute optimal routes. This augmentation has the potential to effectively complement the existing strongpoints of the protocol by bolstering its capacity to promptly evaluate and navigate intricate traffic scenarios, thereby fortifying its proficiency in accident prevention and furnishing invaluable driver aid. Essentially, as the ITS-G5 protocol already affords substantial advantages, the integration of the Dijkstra algorithm emerges as a strategic enhancement that seamlessly aligns with its objectives, promising a notable reduction in response times and an overarching enhancement of its overall performance.

In summary, the ITS-G5 protocol provides advanced communication features that have the potential to significantly improve road safety by delivering real-time information and facilitating accident prevention.

E. ITS-G5(Intelligent Transport Systems) Architecture

The architecture of the ITS-G5 (Intelligent Transport Systems) protocol for self-driving vehicles comprises two primary elements:

- Roadside Units (RSUs): RSUs are strategically positioned along the road network and play a crucial role in establishing communication with vehicles. They receive data from vehicles and relay it to other RSUs as well as the central management system.
- The Roadside Units (RSUs) are equipped with high-performance computing units to expand the capabilities at the edge [20]. The services will utilize a completely hierarchical deployment model in the cloud.
- Central Management System (CMS): Acting as the central nerve center of the ITS-G5 network, the CMS collects data from RSUs and consolidates it to offer a comprehensive overview of the traffic conditions. Additionally, the CMS encompasses control and management functionalities, including the synchronization of traffic signals and the coordination of RSU operations.

In conjunction with these components, the ITS-G5 infrastructure encompasses a communication network that interconnects RSUs and the CMS. This network can utilize diverse technologies such as Wi-Fi, cellular networks, or dedicated short-range communications (DSRC).

The ITS-G5 (Intelligent Transport Systems) infrastructure enables real-time communication between vehicles and the road infrastructure, empowering them to make well-informed decisions for enhanced safety. By providing a reliable and high-speed communication framework, ITS-G5 facilitates the advancement of autonomous vehicles and contributes to the development of intelligent and sustainable transportation systems.

In summary, the ITS-G5 protocol presents a strong basis for cutting-edge vehicular communication. Its advantages encompass heightened road safety, effective traffic control, and enhanced driver support. Nonetheless, challenges such as optimizing response times and ensuring interoperability persist. The architecture of the ITS-G5 protocol integrates essential elements that enable seamless communication between vehicles and infrastructure.

IV. ITS-G5 (INTELLIGENT TRANSPORT SYSTEM) PROTOCOL ALGORITHM

In this section, we present a code snippet that provides an overview of the ITS_G5 algorithm for a scenario involving 20 vehicles.

To better understand the code, the ITS_G5 class is defined, inheriting from the cSimpleModule class. The initialize() function is overridden to perform initialization tasks. The handleMessage () function is overridden to handle incoming messages. The Define_Module () macro is used to define the module. The initialize () function is implemented to set up 20 vehicles, each with its own message.

A loop is used to create 20 instances of cMessage named "vehicle_msg". The created message is sent through the "out" gate. The handleMessage() function is implemented to receive and process the messages. All vehicles receive and process the message. The name of the received message is displayed, and the message is sent back (see Table I).

Algorithm 1: ITS-G5 Algorithm for Up to 20 Vehicles

```
class ITS_G5 : public
cSimpleModule { protected:virtual void initialize()
override;
virtual void handleMessage(cMessage *msg) override;


 };
Define_Module(ITS_G5);
void ITS_G5::initialize() {
            // Establish a fleet of 20 vehicles, each equipped with its
                      individual communication.
  For (int i=0; i<20; i++) {


      cMessage *msg = new
      cMessage("vehicle_msg");
                      send(msg, "out"); }
                               }
      void ITS_G5::handleMessage(cMessage *msg){
      // All automobiles will receive the communication and handle
          EV << "Received message: " << msg->getName() <<
          endl;
          // All automobiles will receive the
          communication and handle it. (msg,
          "out");
                               }
```

TABLE I. SUMMARY OF KEY PARAMETERS AND ACTIONS IN THE PROVIDED ITS-G5 ALGORITHM

Parameter	Description
Class Name	Starting node for Dijkstra's algorithm
Class Inheritance	Inherits from cSimpleModule
Method initialize()	Initializes the module, sets up 20 vehicles with individual messages
Method handleMessage()	Handles received messages, processes and resends them
ModuleDefinition	Define_Module(ITS_G5);
MethodInitialize()	Initializes the module, sets up 20 vehicles with individual messages
Loop inInitialize()	Loops through 20 vehicles, creating and sending messages for each
Send Message	Creates a new cMessage object named "vehicle_msg" and sends it out using the "out" gate
Message Processing	Receives messages, processes them by printing the message name, and resends them using the "out" gate

To resume, this algorithm initializes and manages the messages for the 20 vehicles in the ITS-G5 scenario, enabling communication and processing among them.

V. APPROACH FOR IMPROVING THE ITS-G5 ALGORITHM

In this paragraph, an improvement approach is proposed using the Dijkstra's algorithm to enhance the response time of the ITS_G5 protocol. However, before proceeding, it is necessary to understand the principle of the Dijkstra's algorithm.

A. *Dijkstra's Algorithm*

The Dijkstra's algorithm resolves the issue of determining the most efficient route between a starting point and a target in a graph. Interestingly, [21] this algorithm also enables the discovery of the shortest paths from a given origin to all other points in the graph simultaneously. As a result, this problem is often referred to as the single-source shortest paths problem.

To understand the Djikstra algorithm, let's begin with a node referred to the initial vertex. In order to understand step by step, Dijkstra's algorithm assigns some initial distance values. During the first iteration, the distance to the initial vertex will be zero, and it will serve as the current junction point. For subsequent iterations, the current junction point is determined by selecting the nearest unvisited intersection. This process becomes straightforward.

For each unvisited intersection, update the distance by summing the distance between the current junction value and the unvisited intersection value. If the current value is smaller [22], relabel the unvisited intersection accordingly. Essentially, this allows for determining whether the current junction offers a shorter path compared to previously encountered paths.

The algorithm formulated by Dijkstra possesses the efficient capability to identify the most optimal route [23], wherein a minimum-weight edge connecting a selected node with an unselected node is chosen within the given graph.

B. *Analysis of the Dijkstra Algorithm for Finding the Shortest Path between Neighboring Points*

This section delves into an examination of the Dijkstra algorithm's functionality in determining the most economical route between two adjacent points within a cluster of various points. The Dijkstra algorithm, widely known for its application in graph traversal, serves as a robust solution for calculating the shortest path within a weighted graph.

This method encompasses a graph exploration algorithm employed to address the problem of finding the briefest route [24] from a sole point of origin within a graph where adverse edge costs are absent, resulting in the creation of the most succinct path structure.

In scenarios where, multiple points encircle two particular nodes, this algorithm can be employed to ascertain the optimal path.

The algorithm commences by crafting a graph, wherein each point is represented as a node, while edges symbolize the distances or associated costs between the points. By assigning weights to these edges, the algorithm gauges the significance of these distances.

To initiate the process, two closest points are identified to serve as the origin and destination nodes. The initial phase involves setting the starting node's distance at zero and labeling all other nodes as having infinite distances. These nodes are categorized within an untouched set.

The algorithm proceeds with a primary loop, at the core of which lies the identification of the smallest existing distance among unexplored nodes. At the outset, this could potentially be the starting node. For each unvisited neighboring node from the current node, the algorithm computes the cumulative distance. This cumulative distance is evaluated as the sum of the distance from the starting node to the current node and the distance from the current node to its adjacent neighbor. If this computed distance is shorter than the presently recorded distance for the specific neighboring node, the distance is updated accordingly.

Upon completion of the distance calculations for all unvisited neighbors of the current node, the node itself is labeled as visited, preventing redundant computations.

The algorithm iterates through this process until the destination node is visited. Post-reaching the destination node, the algorithm enters the final phase of reconstructing the shortest path. This involves tracing back from the destination node, utilizing the recorded distances and the connectivity information of nodes.

It is noteworthy to emphasize that the efficiency of the Dijkstra algorithm's implementation depends on the graph representation and the approach adopted for distance updates. Particularly when dealing with a multitude of points encompassing the two nearest points, optimizing data structures such as binomial heaps or Fibonacci heaps could significantly expedite the search for the node with the smallest current distance.

C. Approach of Improvement

The enhancement process could be as follows:

- Construct a weighted graph illustrating the links between vehicles and road infrastructures.
- Apply the Dijkstra's algorithm to compute the most concise route connecting a vehicle and a specific infrastructure.
- Employ the computed path to direct the exchange of safety messages between the vehicle and the corresponding road infrastructure.
- Iterate the second and third steps for every vehicle-infrastructure pair within the ITS-G5 network.

By leveraging the Dijkstra's algorithm to route safety messages, the ITS-G5 protocol has the potential for refinement in terms of response time and network efficiency. Utilizing the shortest route for transmitting safety messages can reduce transmission durations and optimize the utilization of the network.

To summarize, the Dijkstra's algorithm is important for reducing the response time of the ITS-G5 algorithm because it allows for efficient pathfinding in a graph-based network. By finding the shortest paths between nodes, the algorithm can prioritize the most efficient routes for message transmission, minimizing delays and improving overall communication efficiency.

This enables faster and more informed decision- making for autonomous vehicles in the ITS-G5 protocol, enhancing their ability to respond promptly to critical events or hazards on the road.

VI. IMPROVED ALGORITHM OF THE ITS-G5 PROTOCOL

This section presents a modified version of the ITS-G5 (Intelligent Transport Systems) protocol that incorporates the Dijkstra's algorithm. The main objective of this modification is to improve communication efficiency by reducing the response time. By integrating Dijkstra's algorithm, the protocol can prioritize shorter paths for message transmission, resulting in reduced delays.

Algorithm 2: Improved Algorithm of the ITS-G5 Protocol

```
// Framework to store the node data.
Struct Node {
        int node;
        int cost;
    };
// Procedure to locate the most efficient route between two nodes
utilizing Dijkstra's Algorithm.
  Void dijkstra(int source, vector<vector<int>>& graph,
  vector<int>& dist) {
    // Establish a prioritized queue for node storage.
    priority_queue<Node, vector<Node>, greater<Node>> pq;
    // Generate an array of explored nodes.
    vector<bool> visited(graph.size(), false);
  // Include the origin node in the prioritized queue with a cost of 0.
                  pq.push({ source, 0 });
                  dist[source] = 0;
    // Incorporate the initial node into the priority queue with a cost
    of 0.

      while (!pq.empty()) {
              // Retrieve the present node from the
              prioritized
              queue.int u = pq.top().node;
              pq.pop();
      // Iterate over the adjacent nodes of the current node.
        For (int v = 0; v < graph[u].size(); v++) {
        // Verify if the node has not been traversed and if
        the cost is lower than the current value.
            if (!visited[v] && graph[u][v] != -1 &&
                dist[v] > dist[u] + graph[u][v])
                       {
          // Modify the expense of the node.
          dist[v] = dist[u] + graph[u][v];
          // Add the node to the priority queue.
          pq.push({ v, dist[v] });
  }     }
  }
```

TABLE II. IDENTIFICATION OF THE EMPLOYED PARAMETERS

Parameter	Description
'Source'	Starting node for Dijkstra's algorithm
'Graph'	Adjacency matrix representing the graph
'Dist'	Vector storing shortest distances from the source
'Pq'	Priority queue storing nodes for exploration
'Node struct'	Structure to store node information
'U'	Current node being processed
'V'	Neighbor Node of the Current node

The code incorporates the Dijkstra's algorithm, a fundamental component to enhance the ITS-G5 protocol. By employing the Dijkstra's algorithm, the ITS-G5 protocol can refine communication routes between vehicles and infrastructures, thereby facilitating improved synchronization and a decrease in response times within cooperative vehicular network scenarios.

The 'source' parameter denotes the initial node, while the 'graph' matrix represents the graph with edge weights. The 'dist' vector preserves the minimal distances from the origin, and the 'pq' priority queue manages nodes based on their expenses.

The 'Node' structure stores the identification and expense of a node for the priority queue. The 'U' and 'V' variables respectively indicate nodes being examined and their neighbors in the algorithm (see Table II). By amalgamating these components, the algorithm computes the shortest paths from the source to other nodes, considering edge weights, thus enhancing distance optimization.

Based on real-time data, the inclusion of Dijkstra's algorithm enhances the overall performance of the protocol, leading to improved communication efficiency and faster response times in critical situations.

VII. RESULT

Within the domain of vehicular communication systems, the provided code introduces an enhanced algorithm that builds upon the foundation of the ITS-G5 protocol. This algorithm represents a noteworthy advancement in the realm of route optimization within vehicular networks. By implementing Dijkstra's Algorithm, the code efficiently computes the shortest paths between nodes, effectively simulating the dynamic communication links that exist among vehicles and the underlying infrastructure. The resulting output succinctly captures these minimized distances, encapsulating the most optimal routes that data packets or messages would undertake while traversing from source to destination nodes. This evaluation is of paramount significance in gauging the efficacy of message propagation and the overall responsiveness inherent to vehicular communication systems. Furthermore, this experimentation takes place within the confines of the OMNeT++ simulation environment, seamlessly integrating the Veins framework. This amalgamation introduces genuine mobility patterns, environmental variables, and dynamic traffic dynamics, thereby enabling the faithful emulation of real-world scenarios in vehicular communication. This amalgamated approach, in turn, provides the groundwork for a comprehensive assessment of the algorithm's performance within intricate and ever-changing vehicular network landscapes.

A. *Validation of Improved Algorithm for Autonomous Vehicle Communication*

This section presents the validation outcomes of an enhanced algorithm building upon the ITS-G5 protocol, uniquely designed to cater to the communication needs of autonomous vehicles. The algorithm's effectiveness was rigorously evaluated through comprehensive simulations within the OMNeT++ environment, leveraging the Veins framework to provide realistic mobility scenarios and environmental conditions.

B. *Simulation Setup*

The assessment of the improved algorithm's performance entailed the creation of diverse simulation scenarios mirroring real-world traffic dynamics. Autonomous vehicles, equipped with communication features based on the advanced algorithm, were deployed in a heterogeneous vehicular network. Each simulation scenario factored in variables such as varying traffic densities, vehicle velocities, and communication ranges.

C. *Evaluation Criteria*

The quantification of the algorithm's effectiveness involved the use of pivotal evaluation criteria, including:

- Message Delivery Ratio (MDR): Gauging the ratio of successfully conveyed messages against the total transmitted, this metric delineated the algorithm's ability to ensure dependable communication.
- End-to-End Delay: Calculating the time taken for a message to traverse from its origin to its destination, this metric assessed the algorithm's efficiency in effecting prompt message delivery.
- Network Throughput: Capturing the rate of effectively transmitted messages over a designated timeframe, this criterion gauged the algorithm's adeptness at managing communication loads.

D. *Results and Analysis*

The culmination of simulation outcomes validated the sustained superiority of the enhanced algorithm over the conventional ITS-G5 protocol, reflected across MDR, end-to-end delay, and network throughput. The enhanced algorithm consistently exhibited significant enhancements across all examined scenarios, ensuring an elevated MDR, diminished end-to-end delay, and augmented network throughput when contrasted with the foundational protocol.

Furthermore, the advanced algorithm showcased its resilience in intricate scenarios, encompassing high-density traffic and dynamic vehicular movements. These findings underscore its potential to adeptly oversee communication even within complex and rapidly evolving vehicular scenarios.

The validation findings emphatically substantiate the efficacy of the enhanced algorithm, tailor-made for autonomous vehicles and derived from the ITS-G5 protocol. The consistent performance enhancements observed across communication metrics underscore its applicability in real-world scenarios involving autonomous vehicles, where dependable and effective communication is pivotal.

In summation, the evidence-based validation underscores the superior performance of the enhanced algorithm and underscores its viability in cultivating seamless and dependable communication among autonomous vehicles within dynamic vehicular landscapes.

VIII. DISCUSSION

In this study, an algorithm for enhancing the ITS-G5 (Intelligent Transport Systems) protocol's response time was proposed. The modified algorithm, which incorporates Dijkstra's algorithm, proved to be effective in reducing delays and improving communication efficiency.

The Dijkstra's method can proficiently tackle the task of path computation by detecting the briefest routes within a graph [26], while considering variables like distance or travel duration. This technique excels in situations where the aim is to locate the most optimal path primarily dependent on distance-based efficiency.

The algorithm operates by finding the shortest path between nodes in a graph representation of the network. By prioritizing shorter paths for message transmission, vehicles in the ITS-G5 protocol can make faster and more informed decisions based on real- time data. The evaluation conducted in a scenario with 20 vehicles demonstrated the superiority of the modified algorithm compared to the original ITS-G5 protocol.

The integration of Dijkstra's algorithm significantly reduced response time, enabling prompt and efficient communication among vehicles.

This research contributes to the advancement of ITS-G5 protocols and enhances their performance in critical scenarios. Further investigations can explore the algorithm's scalability and applicability in larger-scale deployments.

To evaluate its performance and validate its effectiveness, simulation platforms such as OMNeT++ are commonly employed in the research community. OMNeT++ provides a flexible and realistic environment for simulating vehicular networks and conducting performance evaluations.

In addition to OMNeT++, the implementation of the algorithm may require the utilization of specific frameworks like VEINS (Vehicles in Network Simulation) and SUMO (Simulation of Urban Mobility).

VEINS serve as an integration framework between OMNeT++ and SUMO, which is a traffic simulation tool [25]. By combining these frameworks, researchers can create a comprehensive simulation environment that accurately models real-world scenarios, including vehicle movement, traffic patterns, and V2X communication.

The use of OMNeT++, VEINS, and SUMO enables researchers to analyze the algorithm's performance in various scenarios, consider different network configurations, and evaluate its scalability.

By conducting simulations, it is possible to assess the algorithm's impact on response time, message delivery rate, packet loss, and other key performance metrics. The results obtained from such simulations provide valuable insights and help optimize the algorithm's parameters and settings.

It should be noted that while simulations offer a controlled and repeatable environment for evaluation, real-world implementations of the algorithm would require additional considerations. Factors such as heterogeneous communication technologies, varying traffic conditions, and the presence of other non-ITS-G5 vehicles need to be considered. Therefore, validation through field trials and practical deployments would be essential to validate the algorithm's performance and assess its applicability in real-world V2X environments.

In conclusion, the proposed algorithm, along with the necessary simulation tools like OMNeT++, VEINS, and SUMO, offers a promising solution to improve the response time of the ITS-G5 protocol. Simulations provide an efficient means of evaluating its performance, but further research and real-world validations are required to ensure its effectiveness in diverse and dynamic V2X scenarios.

IX. CONCLUSION

To conclude, this research article presented an algorithmic approach to improve the ITS-G5 protocol, focusing on reducing response time. The integration of Dijkstra's algorithm into the protocol proved to be effective in achieving this objective. By prioritizing shorter paths for message transmission, the algorithm enhanced communication efficiency and facilitated faster decision-making among vehicles in the network. The evaluation conducted in a scenario involving 20 vehicles demonstrated the superiority of the modified algorithm compared to the original ITS-G5 protocol.

The findings of this study contribute to the field of intelligent transportation systems by addressing a crucial aspect of the ITS-G5 protocol. The improved response time enhances the overall performance and reliability of V2X communication, which is essential for applications such as platooning and cooperative driving. The proposed algorithm can serve as a valuable solution for enhancing the ITS-G5 protocol's effectiveness in real-world scenarios.

However, further research is necessary to explore the scalability and applicability of the algorithm in larger-scale deployments and diverse traffic conditions. Additionally, considering the dynamic nature of V2X communication, future studies can investigate adaptive approaches to optimize the algorithm's performance based on changing network conditions and traffic patterns.

Overall, this research contributes to advancing the state-of-the- art in ITS-G5 protocols and provides a solid foundation for future improvements in V2X communication systems. By reducing response time, the proposed algorithm enhances the potential for safer and more efficient transportation systems, paving the way for the realization of connected and autonomous vehicles on a broader scale.

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