Multi-Agent Based Framework for Cooperative Traffic Management in C-ITS System

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Keywords: C-ITS, Multi-Agent Systems, Traffic Management, Communication, Congestion Detection, Decision-Making.

Abstract: The continual growth in road traffic poses significant challenges to effective traffic management, necessitating innovative solutions such as Cooperative Intelligent Transport Systems (C-ITS). This paper introduces a novel multi-agent based model designed to address road traffic management in C-ITS systems. Our approach aims to reduce congestion and enhance driver decision-making by leveraging dynamic communication and information exchange between vehicles and infrastructure. Our multi-agent system is intricately designed to play specific roles in managing traffic flow. Through real-time execution using a C-ITS road safety case study focused on warning accidents, we evaluate the performance of our architecture through key metrics including mean travel time and mean speed in the C-ITS system. The innovative aspects of our approach lie in the integration of multi-agent systems in such a system, providing a significant advancement in the field of C-ITS road traffic management. By detailing the instantiation of our system and emphasizing concrete services, we contribute to the broader goal of improving road safety and traffic efficiency in urban environments.

1 INTRODUCTION

For decades, the transportation system has tirelessly pursued advancements in efficiency, environmental protection, and safety in traffic management. However, the escalating number of vehicles over the years, as highlighted by recent statistics (Davis and Boundy, 2021), claims that *"since 1900, the number of vehicles per 1,000 persons in the United States has increased dramatically. After reaching a peak of 844.5 in 2007, the number fell but then started to rise in 2012. In the United States in 2018, there were 836.3 vehicles per 1,000 persons"*. The surge in vehicle numbers necessitates a paradigm shift towards improved road traffic management, a critical aspect given its direct impact on daily life and environmental quality. Better road traffic management must be implemented due to the rise in vehicle numbers over time. To ensure that traffic is maintained, traffic management is largely concerned with service management. Services are the main focus of C-ITS systems. C-ITS, a cutting-edge extension of Intelligent Transport Systems (ITS), emerges as a pivotal technology for augmenting traffic efficiency, road safety, and environmental sustainability and providing comfort needs for end-users (driver) (Li et al., 2022). C-ITS leverages Information and Communication Technologies (ICT) to facilitate real-time information exchange among vehicles (Vehicle-to-Vehicle, V2V) and between vehicles and infrastructure (Vehicle-to-Infrastructure, V2I). This communication is facilitated by the On-Board Units (OBU) in connected vehicles and the Road Side Units (RSU) within the infrastructure, representing the C-ITS subsystems. Therefore, C-ITS represents a transformative approach to better transportation through the integration of smart C-ITS sub-systems and advanced communication technologies that specify how they interact. In this interaction, C-ITS sub-systems communicate and cooperate based on international standards such as CEN, ISO, and ETSI. Therefore, C-ITS makes it possible to go a step further in providing real-time information and tailored control strategies to specific drivers. C-ITS excels in collecting and disseminating real-time messages about the road environment directly to drivers, thereby enhancing decision-making. This connectivity can ameliorate

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Aloui, A., Hachicha, H. and Zagrouba, E.
Multi-Agent Based Framework for Cooperative Traffic Management in C-ITS System.
DOI: 10.5220/0012468300003636

In *Proceedings of the 16th International Conference on Agents and Artificial Intelligence (ICAART 2024) - Volume 1*, pages 420-427
ISBN: 978-989-758-680-4; ISSN: 2184-433X

road safety and efficiency, exemplified by services offering advice, warnings, or actions. Despite the wide-ranging benefits of C-ITS development and deployment, challenges in traffic monitoring, C-ITS communication, and security persist as traffic management issues. This paper focuses specifically on the C-ITS traffic management challenge, recognizing its potential to impede traffic efficiency and compromise service delivery to drivers if not adeptly addressed. Our key contribution lies in leveraging a multi-agent system to model and simulate the complex dynamics of road traffic. Unlike traditional approaches, which often rely on centralized control mechanisms, our methodology empowers individual agents to make autonomous decisions based on real-time information. This decentralized approach enables a more adaptive and responsive system, particularly crucial during unforeseen events such as accidents or road works. Our Contributions are summarised as follows:

- Propose a C-ITS architecture with a cluster decomposition to facilitate traffic management and increase road safety and traffic efficiency by controlling and monitoring vehicles.
- Propose a new Multi-agent framework for cooperative traffic management in C-ITS systems to alleviate traffic congestion and improve driver decision-making

This paper is structured in four sections: the first section introduces our paper. The second section enumerates and details the different related work as well as a brief description of our contribution. The third section describes our architecture. The experimentation is presented in section fourth. We conclude our research work in the last section with some future perspectives.

2 RELATED WORK

Literature explores Multi-Agent Systems (MAS) to support C-ITS, addressing communication issues, especially in Vehicle Ad-Hoc Networks (VANET) as the core part of such a system and traffic control for better traffic management. For instance, in (Devangavi and Gupta, 2017) agents collaborate on path discovery using Bezier curves for multipath routing and mobile agents for reducing communication costs. The model outperforms in transmission time, number of multipath computed, communication overhead, and packet delivery ratio, but the short simulation time of 600 seconds warrants further testing in dynamic traffic scenarios and complex situations like closed lanes or segments.

Some research focuses on using MAS to address C-ITS traffic management in all the systems including its components. For instance, in (Zarari et al., 2018) a generic architecture for the deployment of C-ITS within a MAS dedicated to VANET is proposed. The model utilises commonly stationary and mobile agents and is based on a formal representation but lacks evaluation of performance metrics and C-ITS service management which is the main concern of the C-ITS system. In the work of (Zouari et al., 2021) a Cooperative MAS for Road Traffic Decision Making based on Hierarchical Interval Type-2 Fuzzy System (HIT2FS) is proposed, showing positive results in path flow and mean travel time, yet the short 360-second simulation time calls for longer testing.

Other research works focus on specific components of C-ITS using MAS. In (Guériau et al., 2016), the main focus was on the RSU. An agent-based model focusing on the decision-making of the C-ITS system to RSU components as discretized agents to deliver messages to vehicles. They propose a reinforcement learning process model to send these messages based on a k-means classification. Further details are needed in this work such as reinforcement learning algorithms used. In the research work of (Hamdani et al., 2022), the main focus was on Smart Road Signs (SRS) which is responsible for Traffic monitoring and sending warnings to drivers. They propose route guidance to reduce travel time based on mobile and stationary agents. However, this work was not evaluated. The work of (Belbachir et al., 2019) focuses on traffic lights and proposes a self-adaptive mechanism to regulate traffic lights via I2I communication. This work lacks scalability, it is specific at intersections to deal with specific situations(congestion). In the work of (Naderi et al., 2023), authors propose a hierarchical traffic light-aware routing scheme using reinforcement learning at the two-level RSU and SDN to adjust their policies depending on the variation of time. In (Teixeira et al., 2020) the focus is on autonomous vehicles using Belief-Desire-Intention (BDI) agents to make decisions within their cognitive capacities, with scalability concerns and limited scenario testing. Added to that, BDI agents are expensive in time execution. If the number of vehicles increases, the execution time will be much higher.

Other research work is focusing on congestion management due to warnings. We cite as an example (Hamidi and Kamankesh, 2018) (Perez-Murueta et al., 2019). For example, MAS was applied in (Hamidi and Kamankesh, 2018) to deal with emergency warnings. Their proposal was based on the increase in the quality of the entire path network. Similarly in (Perez-Murueta et al., 2019), a model was

designed to deal with congestion issues based on a MAS. Authors utilize real-time probe vehicle data and deep learning for traffic state prediction. The rerouting process is done with entropy entropy-balanced k shortest path for vehicles. However, the lack of evaluation against existing research limits the assessment of their approach's effectiveness.
The main difference between our proposal and the approaches analyzed is that we will delve into the rich value that multi-agent systems bring to the modeling, exploration, and optimization of the complex problems inherent in the different C-ITS subsystems. Our proposal focuses on the limits of the analyzed approaches for enhancing C-ITS architectures using MAS, emphasizing adaptability for flexible traffic management and services. This approach goes beyond cooperation, aiming for a holistic solution to the challenges of modern transportation systems.

3 PROPOSED ARCHITECTURE

3.1 Hierarchical C-ITS Architecture

The proposed hierarchical C-ITS architecture, inspired by successful deployment projects, and with respect to the standardization defined in the C-ITS reference architecture (Dajsuren et al., 2017), implies a set of components (C-ITS subsystems), which are responsible for the operational aspect of the C-ITS system based on their features and communication, is structured into three levels (Fig. 1): Center System, Infrastructure, and Urban Road. Each level plays a crucial role in ensuring efficient traffic management and enhancing road safety.

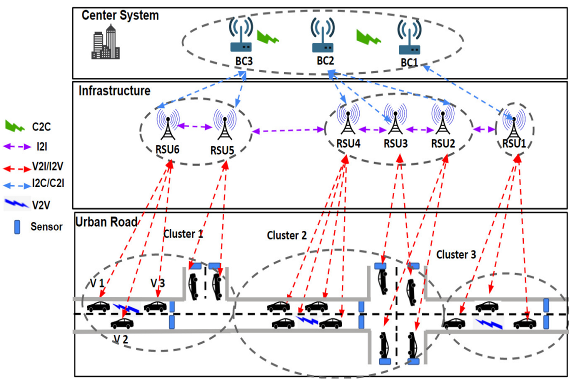

Figure 1: An overview of the proposed C-ITS system architecture.

1. Center System: is the highest level of the architecture aiming to control traffic. It comprises several Base Controllers (BC), each one representing a city. BCs facilitate communication with each other through C2C communication, with RSUs in the same city (I2C/C2I). Geographic considerations ensure that each cluster represents a coherent and manageable section of the road network.
2. Infrastructure. The Infrastructure level includes RSUs as essential fixed components for guiding and monitoring traffic. Their significance lies in supporting local traffic management, addressing intersection management, speed control, warning systems, parking management, and overall traffic monitoring. Details about RSU subsystems and functionalities are elaborated in (Dajsuren et al., 2017). Each RSU covers a specific zone, serving as a data collection point for real-time monitoring and analysis of road conditions.
3. Urban Road: is the low level of the architecture equipped with a range of sensors such as loop detectors, cameras, etc, and comprises a decomposition of the road to clusters. More details about cluster decomposition are presented in our previous research work (Aloui et al., 2021). Each cluster refers to one BC and comprises a set of RSUs and vehicles equipped with the C-ITS system. This implementation of C-ITS in vehicles enables interaction between infrastructure via the RSUs and vehicles via their OBUs (V2I/I2V) as well as the interaction between vehicles (V2V). RSUs actively provide data related to traffic flow, congestion, and incidents, which is then processed collaboratively with BCs to set and adjust rules effectively.

The development and deployment strategy of the C-ITS systems hinges on the implementation of specific C-ITS applications within each sub-system. A C-ITS application is a specific use case that falls under a particular C-ITS service. To optimize these applications, our proposal advocates for the utilization of agents as the fundamental building blocks of C-ITS sub-systems. Each C-ITS application is conceptualized, designed, and implemented as a multi-agent system, harnessing the power of agent-based technology to enhance the system's efficiency, communication, and decision-making. This innovative approach aligns with the dynamic nature of traffic management, leveraging agent-based systems to create a responsive, collaborative, and adaptable framework for C-ITS. The subsequent sections delve deeper into the specifics of the multi-agent system implementation.

3.2 Urban Road Architecture Based on the Multi-Agent System in C-ITS

The adoption of a MAS in the proposed C-ITS architecture is strategically justified for its capacity to enhance decentralized decision-making, adaptability to local contexts, and efficient information sharing among intelligent agents. The MAS enables decentralized decision-making, allowing agents to autonomously respond to local conditions.

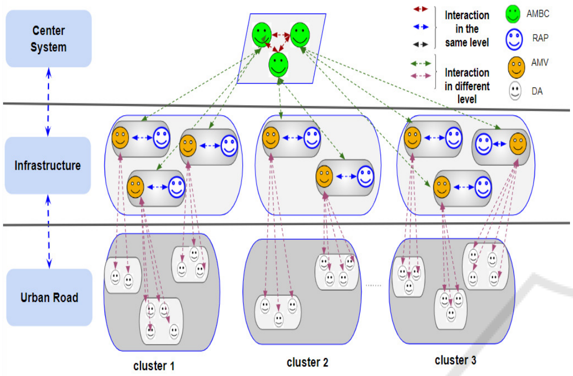

Figure 2: The distributed C-ITS architecture based on MAS.

Table 1: Roles of each agents.

Agents	Role
AMBC	Have a global view in the entire traffic. It aims to propose the relevant rules to prevent congestion due to warnings.
RAP	Check traffic conditions. It is responsible for detecting congestion situations. It communicates with both AMV and AMBC and informs them every predefined time t about the traffic condition
AMV	Checks the subscription and unsubscription of drivers in their covered zone. It communicates with RAP, AMBC and disseminates services to subscribed DA
DA	Interact with AMV for receiving warnings, advice, and rules and transmitting them to other DA as well as proposing recommendations.

Our proposed MAS employs a set of stationary agents, which handle the core functionalities within each C-ITS subsystem, and we propose the integration of mobile agents in case of connection interruption in different C-ITS subsystems.

Figure (Fig. 2) illustrates the architecture of the C-ITS system based on MAS Our multi-agent-based architecture comprises four agents that cooperate to manage and deploy C-ITS services.

Within the vehicle subsystem, the DA (Driver Agent) is tasked with receiving services and facilitating real-time information exchange with other DAs. In the RSU subsystem, the AMV (Agent Manager Vehicle) takes on the responsibility of receiving services and sharing traffic-related data with the RAP (Road Agent Parent). Similarly, within the BC subsystem, the AMBC (Agent Manager Base Controller) analyzes traffic data, receives real-time information and collaborates with BCs ' agents and RSUs' agents to enhance overall system efficiency. This agent-based architecture ensures dynamic and responsive road safety, fostering effective communication and information sharing across the entire system. The role of each agent is described in (tab. 1). We define the operation of the C-ITS system as consisting of the following different steps represented in (Fig. 3).

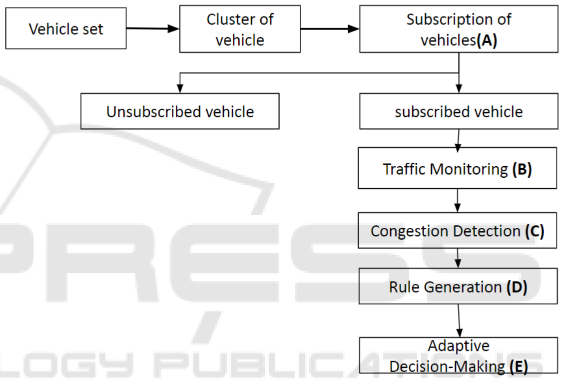

Figure 3: Flowchart of the proposed method.

A. Subscription of Vehicles

In the dynamic landscape of C-ITS, the ”Subscription of Vehicles” process plays a pivotal role, forming a crucial link in the efficient management of traffic and the delivery of essential C-ITS services. Vehicles, upon entering the RSU-covered zone, have the option to either subscribe to or unsubscribe from C-ITS services. Subscription entails an agreement to share and receive real-time information, fostering a cooperative and informed traffic environment. Thus, when a vehicle enters a new cluster, the nearest AMV in RSU is responsible for detecting every vehicle. Each subscribed vehicle exchanges information with the DA as well as its parameters (ID, speed, destination. . . .) to monitor and manage traffic information in its covered zone. Unsubscribed vehicles will be detected by road sensors. Every vehicle v_i follows a set of routes represented by the following equation:

$$R = \{r_1, r_2, r_3......r_n\} \quad (1)$$

Each subscribed DA sends a message to the corresponding AMV as follows:

$$msgi = \{id_{v_i}, speed_{v_i}, position_{v_i}, destination_{v_i}, route_i\} \quad (2)$$

Every subscribed vehicle will deploy a C-ITS application according to the corresponding rules. The AMV agent is responsible for detecting and monitoring the set of vehicles as well as deploying C-ITS applications based on rules to the subscribed ones within their DAs.

B. Traffic Monitoring

As vehicles traverse the road network, subscribed DAs continuously exchange real-time information with the corresponding AMV in the RSU. The AMV, responsible for monitoring and managing traffic information in its covered zone, detects events through the analysis of received data. Events can include sudden changes in speed, unexpected stops, or deviations from the planned route. For every predefined interval time t, the AMV computes the density k as follows:

$$k = \frac{N}{L} \quad (3)$$

where N is the number of vehicles and L is the maximum number of vehicles (in units of vehicles per km) computed as follows:

$$L = \frac{Length of road}{avgvehiclelength + min - gap} \quad (4)$$

where $min - gap$ is the safe inter-distance between vehicles and the mean speed V_f for edges ed_i where Ed is presented as follow:

$$ED = \{ed_1, ed_2, ed_3......ed_n\} \quad (5)$$

The mean speed is presented as follows:

$$V_f = \frac{1}{N}\sum_{n=1}^{N} v_n \quad (6)$$

In fact V_f is the mean of speeds of vehicles passing an edge ed_i.

C. Congestion Detection

Based on the computed traffic density and mean speed received by the AMV, the RAP deploys dynamic rules to manage congestion effectively. The RAP aims to detect congestion levels in the RSU coverage area using an Interval Type-1 Fuzzy Logic model (IT1FL). Figure (Fig. 4) illustrates the model with inputs including maximum speed in ed_i[0, 120] and the density of ed_i [0,100], each possessing 'low,' 'medium,' and 'high' membership functions. Complementing this, Figure (Fig. 5) showcases fuzzified input membership functions, providing a visual representation of input membership degrees. We generate the graphical input memberships within the juzzy library (Wagner, 2013). The output of the fuzzy model is the level of congestion in ed_i [0,1] which has three membership functions 'light', 'moderate', and 'heavy'.

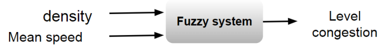

Figure 4: IT1FL model for rule generation of one evaluation.

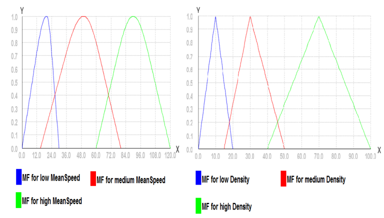

Figure 5: Fuzzified Input membership functions.

Table 2: Rules of the IT1F proposed model.

Rules	Fuzzy Rules
1	IF Density is medium AND Mean Speed is high THEN Level Congestion is heavy.
2	IF Density is medium AND Mean Speed is medium THEN Level Congestion is moderate
3	IF Density is medium AND Mean Speed is low THEN Level Congestion is light

Then, the RAP will define the corresponding rules to the detected congested edges mentioned in (tab. 2).

In a practical scenario, these rules guide the RAP in assessing congestion. Once congested edges are identified, messages are dispatched to both the AMBC and AMVs. The AMV, in turn, notifies subscribed DAs about the congestion, fostering informed decision-making among drivers.

D. Rule Generation

In the rule generation phase, our approach combines insights from congestion detection and Mean Travel Time (MTT) analysis to formulate a dynamic set of rules for efficient traffic management. Using congestion data from the RAP, the AMBC identifies congested edges, categorizing them by severity. Simultaneously, MTT serves as a metric to assess overall travel time performance, establishing thresholds (δ) for acceptable travel times in different scenarios. The AMBC receives from the AMV responsible for the warning event edge position (*position*) about the density (k). Once responding, The AMBC computes MTT every interval time t which is synchronized with the AMV interval time t. We use Greenshield's model (Banks, 2002) for the MTT estimation since it proves its efficiency with well-use by transportation researchers. The idea was that there is a relation between the density and the speed on an edge. Thus, it is computed as follows:

$$T_i = \frac{L_i}{V_i} \tag{7}$$

where

$$V_i = V_f(1 - \frac{K_i}{K_{jam}}) \tag{8}$$

L_i is the length or the same edge ed_i, V_i is the estimated road speed. K_i is the traffic density (vehicles per meter) on ed_i and K_{jam} is the traffic jam density.
The integrated approach dynamically adjusts MTT thresholds based on congestion severity, ensuring adaptive decision-making. For instance, heavy congestion prompts dynamic lane management or rerouting, while exceeding MTT thresholds triggers actions like suggesting alternative routes. By combining congestion and MTT-driven rules, our system achieves comprehensive traffic management, addressing immediate congestion concerns and anticipating potential issues based on travel time trends.

E. Adaptive Decision-Making

The DA receiving the warning service enables drivers to make informed decisions and adapt their travel plans accordingly. Thus, it will compute the distance (distance) between its actual position and the warning event position as follows:

$$distance_{ij} = \sqrt{(pd_i - pd_j)^2 + (pw_i - pw_j)^2} \tag{9}$$

where pd_i and pd_j are the current 2D position of the driver (pd) and pw_i and pw_j are the current 2D position of the warning (pw) where $distance_i > 0$, and $(pd_i, pd_j) \neq (pw_i, pw_j)$. If $distance_{ij} > \beta$ where is a limit value defined by the system, the DA will get the alternative routes, if the $distance_{ij} < \beta$ of limit defined by the system, it will apply imposed rules, the decision-making of the vehicle is executed by the following algorithm.

Driver Agent Algorithm

```
Begin
   1. Each DA  has an Origin and Destination.
   2. While origin != Destination
   3. DA i Send parameters to AMV when
   entering its covered zone
   4. AMV subscribe DA i  via its  parameters
   (id, position, speed, destination) and
   deploy the C-ITS application
   5. If distance between DA i AND event at
   time t >  beta
   6. Asking the AMV about real-time roads
   conditions
   7-  AMV transmits the message to the AMBC
   8- the AMBC send the roads
   condition about MTT
   9- DAi look for the possible alternative
   roads and choose the k-shortest path
   10. else   Apply imposed rules
End.
```

4 CASE STUDY: C-ITS ROAD HAZARD WARNING

To illustrate our proposed model, we choose a C-ITS road hazard warning service to illustrate an accident warning as a C-ITS application. It is important to note here, that the proposed architecture is not specified for accident warning only, but can also be extensible with any other C-ITS application. We aim to demonstrate how to manage traffic information to deliver the drivers the relevant services.
The significance of addressing accidents becomes apparent when considering statistics such as those provided by the National Highway [1] Traffic Safety Administration, which anticipates a 7.342% increase in road accident fatalities to 50 per 1 million inhabitants in the United States in 2022. Similarly, Eurostat [2] reported 42.1 road accident-related fatalities per million people in 2020. These statistics underscore the impact of accidents on road safety and traffic efficiency, emphasizing the need for effective solutions. An accident scenario serves as a challenge to the efficiency of our approach.

4.1 Simulation

For our simulation scenario, we have chosen to replicate the case study previously described in (Bedogni et al., 2015), focusing on the city of Bologna (Fig. 6). As per our architecture, Bologna City is conceptualized as a cluster.

To simulate incidents, such as accidents or road disruptions, we use the capabilities of SUMO [3]. Incidents, in the real world, can encompass collisions, road works, adverse weather causing slow speeds, or simply high traffic flows. There are a few options in SUMO to simulate an accident. In our simulation, we replicate an accident by instructing a vehicle to stop

[1] https://www.nhtsa.gov/
[2] https://ec.europa.eu/eurostat
[3] https://eclipse.dev/sumo/

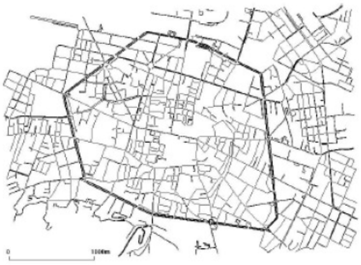

Figure 6: Bologna Map city.

at a defined point along its route and specifying the duration of the halt. TRACI [4] is an API that facilitates real-time interaction between the SUMO interface and the traffic simulation. The simulation runs for a timestep of 60 minutes. Parameters for this example are outlined in (tab. 3). Our MAS is implemented in the JADE platform (Bellifemine et al., 2005). We selected the TRASMAPI (Timóteo et al., 2010) API due to its capability to enable real-time interaction between MAS and the SUMO interface. It establishes a higher level of abstraction between the SUMO API (TRACI) and JADE, facilitating communication between the two tools via TCP sockets. The MAS configuration for handling accident warnings features three designated containers:

Table 3: Maps parameters.

Parameters	Value
Network area	25 km^2.
Total number of road segments	2856
Total number of Traffic lights	99
Total number of junctions	1539
Total number of Vehicles	22000

- **Main Container.** Represents the center system, with one AMBC agent acting as the agent responsible for the Bologna city cluster.
- **Infrastructure Container.** Encompasses RSUs, where two associated agents: the AMV and the RAP function for the operational aspect of an RSU. The Bologne map includes 5 RSUs
- **Urban-Road Container.** Contains DAs created randomly for the simulation scenarios.

4.2 Results and Evaluation

In the experimentation, we are focusing on the strategy proposed for our distributed C-ITS multi-agent based architecture. When the BC detects an accident, the first step is to decide for which RSU it will send the rules. Drivers receiving the warning event will execute the algorithm of the driver agent described in section 3.2. For the K shortest path, the Dijkstra Algorithm (1959) is integrated into the SUMO simulator.

The simulation output presents several statistics for each car, each edge, and each lane. We chose the MTT and the mean speed as metrics in our simulation experiment to evaluate our approach compared to the Original Traffic Trace (OTT) with no cooperation in the sense that the system is centralized. This measurement reveals that our approach leads to better traffic management and fluid traffic. Figure 7 and Figure 8 show the efficiency of our proposed architecture compared to an architecture without the cooperation between the agents. The MTT is smaller and the mean speed is higher in the proposed model than in the other cases which proves how our architecture is beneficial to enhance traffic conditions. The results show how our architecture and placement strategy can impact the MTT and mean speed.

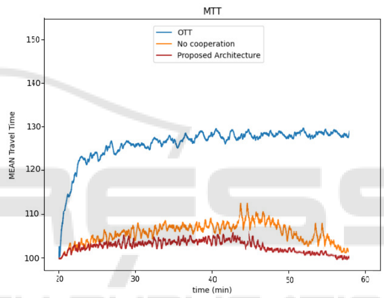

Figure 7: Vehicles mean travel time (from origin to destination).

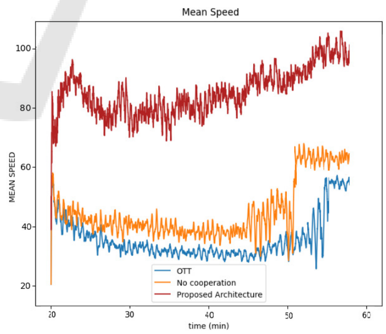

Figure 8: Mean Speed.

5 CONCLUSIONS

In this paper, we propose a generic distributed multi-agent architecture to support C-ITS systems. Our main focus is to manage traffic cooperatively in an urban road environment. MAS in our approach provides distributed traffic monitoring and control as well as a

[4] http://sumo.dlr.de/wiki/TraCI

better management of services. We also integrated the IT1FL model as a decision-making knowledge representation to detect congestion situations due to warning events. It enables handling and modeling uncertainty and makes our system more robust in real-world scenarios. To prove the validation of our approach, we elaborate on a scenario of an accident warning. Our approach outperforms mean travel time and mean speed. There are also other possible research directions to improve the proposed architecture. Additional scenarios are needed to improve the evaluation such as considering more data sets and performance metrics (eg. CO2 emission). We can also include the prediction of unplanned events by using learning methods. In this case, communication at the C-ITS sub-system to identify such a service can be avoided by detecting an event before it even happens. Besides, extending our proposal by considering the security aspect is another challenging and crucial research direction.

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