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A Cyber-Physical System Modelling Framework for an Intelligent Urban Traffic System

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Abstract. This paper presents a novel modelling framework for a component-based architecture that allows validating control strategies for urban traffic networks integrating intelligent traffic control based on cyber-physical transport systems, specifically using V2X (vehicle-to-vehicle) technology. The architecture named *ITSiE* (Integrated tools in a Simulated Environment), is constituted of three components that work in a cooperative way via a middleware, allowing to analyze the traffic behavior in a simulated environment for a defined urban area (selected network streets) and evaluate the impact of using intelligent transport strategies based in V2X. The *first component* named CiudadelaSIM executes the simulation and communicate in real time with the other components; the *second component* named SCPV (Road Proposal Capture System (by its meaning in Spanish), is used to define the simulated scenario (traffic lights, traffic policies, information objects) and the *third component* is a Control Speed System (SpeCo) which allow defining the intelligent strategy, through the capture of multiple techniques and methods to control the speed of the vehicles in a segment with particular features.

Keywords. Multi-agent systems, urban traffic simulator, cyber-physical systems (CPS), vehicular traffic evaluation, V2X technology.

1 Introduction

New technologies, strategies, and devices have been created along these years; which they are indispensable in the development of new systems. It becomes difficult knowing what device or strategy is the most adequate for the system, reason why, before to implement any strategy, technology or system, it is necessary to validate each component, in order to demonstrate its effectiveness; one efficient technique to test any component is the simulation. On this basis, new tools have emerged, which integrate urban traffic control systems to a simulated environment; one of the most popular of them are the V2X technologies (vehicle to X), where X means any object or system. This technology refers to the implementation of Transportation Cyber-Physical System (TCPS) [6, 7]. The objective of V2X technologies is that each vehicle within an urban traffic system communicates through a network with other vehicles, elements, or objects within the same system, as well as the urban infrastructure remaining updated about the current traffic situation [8].

This paper describes a component-based architecture named **ITSiE** (Integrated Tools in a Simulated Environment) that enable to integrate a V2X strategy, multi-agent systems, and a cyber-physical approach. The proposed architecture ITSiE is formed of three main components, the *first one* is an urban traffic simulator called CiudadelaSIM [9], this module present the complete behavior of a scenario, the *second one* is

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a Road Proposal Capture System (SCPV by Spanish abbreviature) [10], which allows capturing the definition of any scenario, SCPV considers traffic objects such as traffic lights, pedestrian's walkways, signs, traffic flow, roads directions, etc., and *the third one* is a Control Speed System (SpeCo). All three components are communicated via a *middleware*.

The proposed architecture allows optimize and model urban traffic using a Cyber-Physical system approach and particularly V2X technology.

A case study is presented. Results consider integration of the V2X technology as elements of an Intelligence Transport System (ITS).

This paper is organized as follows. Section 2 presents some related works. Section 3 describes the components of the architecture. Section 4 presents modelling frameworks and a case study. Section 5 presents results, and finally, section 6 gives some remark conclusions.

2 Related Works

In recent years, the growth of people in urbanized areas has created new challenges about mobility, one of them are alleviate traffic congestion, using new policies, new infrastructure, and technology as main strategies to resolve.

One of the important approaches for traffic urban solutions is V2X technologies, which brings benefits using communication between devices into the infrastructure of a network. This technology is used in the proposal in order to improve the driving experience, decision-making, among others.

The most common use for V2X technologies is to alert drivers about traffic situations that may be barely visible; drivers also may encounter on the road and reduce traffic jams of traffic by providing an accurate view of what is happening in the road network allowing to adapt the traffic management strategy to improve capacity utilization. Another example would be if an accident occurs at the end of a street, where vehicles that approach the area may be alerted in time, before generating a traffic jam, allowing the driver to make appropriate decisions.

The implementation of V2X technology shares information on the status of vehicles, revealing their speed, current position and the direction in which they are traveling [11].

In another work presented in [12], some advantages are mentioned, such as the information collected is used by drivers to make detailed estimations about the current traffic situation in its surroundings. This information results in routes in which the driver can avoid traffic jams by calculating a more intelligent and dynamic way to its destination supported by a GPS navigation system.

The main challenge of the systems that look to reduce the traffic using V2X technologies, is not the technology support, or the size and position of sensors, but rather modeling these systems and evaluating their impact before their implementation. For instance, being aware of the changing nature of the system of a city, it has to take into consideration the behavior of other systems that interact with the implemented strategy and to be aware that integrates modeling not only software level, but external factors, physical and mechanical systems themselves, had already been detected as a need, otherwise, this would represent an empirical and trial and error implementation, by this reason it is why they are required to be well designed to work in real time in a system with hybrid systems that give certainty and reliability of these systems, since a design error could be fatal.

Given the relevance of changing systems, initiatives have been developed in several countries of the world, with the objective of generating scientific and technological foundations to ensure the viability of these systems. For instance, in [13, 14, 15] presents mathematical models and the integration of architectures, regardless the methodologies for the design and modeling of physical and cybernetic systems are developed separately. TCPS is one of the most used approaches to solve these problems. TCPS proposes to model elements that arise from the mixture of two systems such as mechanical or physical, and computer networks, also known as cybernetics, which is focused in the interactions of physical and logical fields; this approach has the objective of monitoring the behavior of the process and actions of physical objects to change the behavior of the environment.

Tools that allow the evaluation of intelligent urban traffic management strategies based on V2X technologies with a TCPS approach have been developed, such is the case of iTetris presented in [16], which is a modular simulation platform for ITS. They combine an urban traffic simulator SUMO (Simulation of Urban Mobility) and the Network Simulator version 3 (NS-3) to validate, monitoring applications of carbon dioxide (CO2) emissions, and traffic efficiency using the protocol TCP/IP.

A V2X Simulation Runtime Infrastructure (VSimRTI) proposed in [17], uses the software for microscope traffic simulations called as Verkehr In Städten - SIMulation (VISSIM) and the Network Simulator JiST/SWAN (Java in Simulation Time/ Scalable Wireless Ad-hoc Networks) to simulate and monitoring CO2 emissions, and the environment.

The results are presented using a graphic scene through a High-Level Architecture (HLA) which is a standard for interoperability among simulations. However, they lack modeling framework that allows the integration of challenges such as, the increase in the magnitude and complexity of a system, interactions with the physical dynamics of the environment and the uncertainty of sensor readings.

Another proposed tool is the Vehicular Network Simulation (VEINS) [18] which is an open source framework based on SUMO and OMNeT++ allowing the inter-communication among the vehicles through the protocol TCP/IP.

There are many challenges for cybernetic and physical systems focused on urban traffic, due to a large number of entities related to each other, making the control of their attributes very complex to control and modify any of their parameters due to the decentralization systems.

The existing approaches for the evaluation of ITS strategies seem to be Ad-Hoc and there is no systematic methodology (modelling framework) or architecture for their construction.

It can be noted that the main cause of the absence of these models under the TCPS approach is the complexity of capturing multiple relationships between the different entities and the external processes involved by ITS strategies.

Therefore, it is required a methodology (modelling framework) that allows to model the integration of these elements and generically enable the integration of one or more components in later stages.

The evaluation of architectures to the integration of TCPS showed that object-oriented paradigm results successfully in terms of simulation time optimization.

In this proposal, a new open source component-based architecture is presented, which the main purpose is to integrate and evaluate functional components easily, the architecture allow to control and management the independent components whilst the interaction between the components is permissible. The architecture is explained in detail in next sections.

3 Architecture of an Integrated Tool in a Simulated Environment (ITSiE)

This section presents basic concepts and the elements that are used by the proposed architecture ITSiE. *UTYiL*: It is an urban traffic modeling language based on XML developed as part of a project for the control of urban traffic [10], whose development was adapted to be used in the architecture of the present paper.

UTYiL is a format for specifying the geographical, topological and transit characteristics of an urban traffic system. UTYiL increases the possibility of sharing the network model of the urban traffic system among the different existing simulation tools when it is described as a network description format.A *segment* in our proposal is defined as a block of a street, which has independent properties of car flow and direction, while an *intersection* is still the crossing of two or more streets.

As we mentioned in the previous section, the proposed architecture is composed of three main components: *SCPV*, *CiudadelaSIM,* and *SpeCo*, explained in detail as follows.

3.1 CiudadelaSIM

CiudadelaSIM is the first and the most important component in the architecture. CiudadelaSIM is a microscopic urban traffic simulation software developed under the multi-agent system paradigm, whose function is to evaluate control strategies and/or vehicular traffic optimization in order to

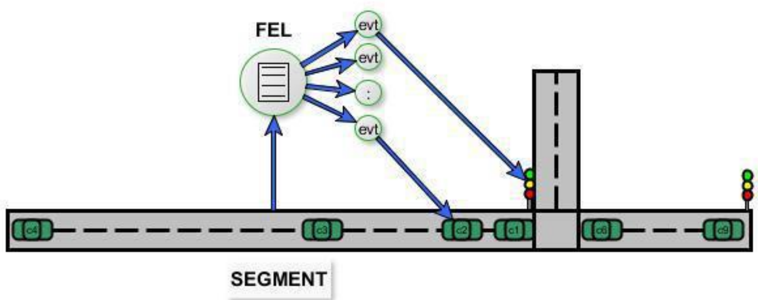

Fig.1. Internal structure of a segment

Table 2. Event Description of a Vehicle

Event	Description
AE (Arrival Event)	Indicates the arrival and creation of a vehicle in a segment.
SE (Stop Event)	The vehicle is in a stopped state.
BE (Begin Event)	Indicates to the object a movement signal and calculates the trajectory until the next obstacle in front of it.
ST (Start Thinking)	This event puts the vehicle in a state of environmental analysis and then makes a decision.
LL (Leave Link)	It represents that the vehicle is at the end of the segment and is ready to exit.
ALE (Arrival Link Event)	Indicates the arrival of the vehicle to a new segment.
DAE (Delay Arrival Event)	It puts the state of waiting for the creation and arrival of a new vehicle, since the vehicle ahead has not yet moved.
DALE (Delay Arrival Link Event)	It puts a state of waiting for the change of segment of a vehicle, since the last vehicle in the segment still retains the position and is waiting for the change of position.
SU (Speed Up)	Increase vehicle speed.
SD (Speed Down)	It reduces the speed of the vehicle.

present the results before being implemented in real urban systems.

It allows modeling the behavior of vehicles, integrating decision-making capacity, the perception of the environment that surrounds it and the configuration of many entities present in the road infrastructure.

CiudadelaSIM is composed of a set of segments and intersections stored in a list call (**FEL**: Future Event List). The list sorts the elements based on the execution time. A *segment* is made up of a series of elements that compound the road infrastructure in which *physical objects* (vehicles), *political physical elements* (traffic lights, traffic signs, and stops), and *political elements* (direction objects and connections between segments) are able to interact with each other (Fig. 1).

Objects are directly related to events; which when executed, modify the state of the object based on the analysis of the interaction of the surrounding environment. Within the event-oriented paradigm, there is a future event list (FEL), which stores the events generated within a segment according to the execution time.

CiudadelaSIM creates a FEL for each segment or intersection, allowing the execution in a modular way within the simulation.

The events that describe the behavior of a vehicle within CiudadelaSIM are presented below in Table I.

CiudadelaSIM is divided in two parts: A *Simulation Machine* and a *Visualization Machine*. In addition, CiudadelaSIM has a flow, density, and vehicular displacement assessment tool, described as follows.

3.1 Simulation Machine

The simulation machine is responsible for interpreting and simulating the UTYiL file sent by SCPV. The simulation machine is connected to a database in PostgreSQL that stores the events generated within the simulation, for further analysis at the end of the simulation.

3.1.1 Display Machine

The visualization machine has the function of visually representing the simulation performed. The process begins with the reading of the UTYiL file for the construction of the road infrastructure; the segments and intersections and the objects within the road infrastructure are drawn. Subsequently, a connection to the PostgreSQL database is established and a query is made to obtain all the events executed within the simulation of the simulation machine, and finally, they are ordered based on the execution time. Visual simulation is obtained, which shows the displacement of the vehicles and the change of light at the traffic lights throughout the simulation period, always governed by a global clock.

CiudadelaSIM is able to configure the density, displacement, and vehicular flow analyzer, obtaining and processing the information of the simulations stored in PostgreSQL.

3.2 Road Proposal Capture System (SCPV)

It is a platform presented in [10] that allows urban traffic control elements to be associated with a road network based on *OpenStreetMap* [19] as a base of geo-referenced; so that the user can select an area of interest that allows him to capture traffic control policies; For example, the addition of new traffic lights, traffic signs, change the waiting time between each change of light, modify the direction of the roads, control the traffic flow at certain times of the day, among others.SCPV captures proposals for urban traffic control using an XML modeling format UTYiL; the generated file is sent to CiudadelaSIM, for the simulation of the traffic objects proposed.

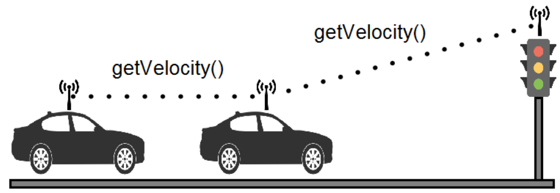

Fig. 2. V2x approach of SpeCo

A user is able to make an urban proposal, once a user finishes capturing the control strategies in the area of interest, he can send a request to start his simulation. To this end, through SCPV, the geo-referenced OpenStreetMap information and the control information are converted into a language called UTYiL. This description is sent to CiudadelaSIM, where it is interpreted and executed. At the end of the simulation, CiudadelaSIM informs to SCPV the results, the user to consult the information about density and flow in each segment.

3.3 Speed Control (SpeCo)

For this module, vehicles (V) and traffic lights (TL) are considered as two types of agents, which each kind has capabilities and defined behaviors inside a controlled environment (segments). It is considered the communication between agents. Every V-agent is able to communicate with TL-agents and V-agents, and vice versa.

In this component, the integration of SCPV is performed to describe which segments of the network simulation are under control of the control system speed (SpeCo), that is, once the vehicle enters a segment with a control system associated speeds, the system will control its speed.SpeCo modifies the vehicle speeds into a segment in an automatic manner, based on the traffic light state to improve the flow of the traffic. SpeCo serves as a tool for speed control of V-agents, and uses the V2X approach for the interaction between Vehicle-Traffic lights (V2TL), and Vehicle-Vehicle (V2V),

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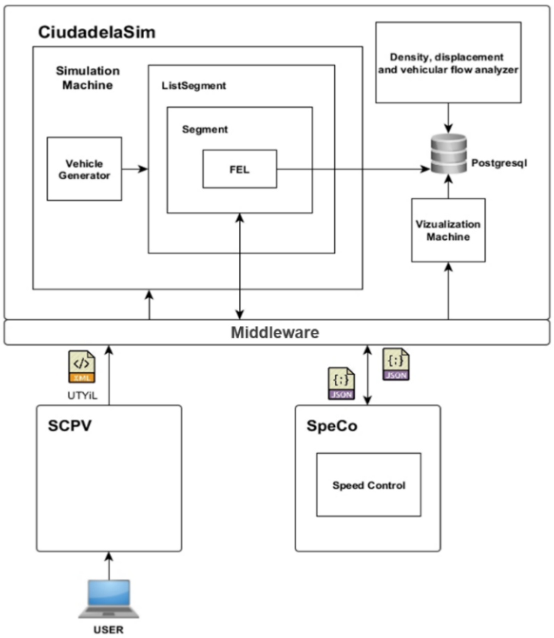

Fig.3. Proposed architecture ITSiE

where the vehicle located at the beginning of the queue of a street consults with the traffic light the times of change of light to adjust its speed and maintain a constant displacement along its journey through the street without stopping, subsequently.

The following vehicles begin their journey with the predetermined speed until reaching the initial vehicle of the queue and coupling to its speed (See Fig. 2). The proposed architecture ITSiE presented in Fig. 3 starts with a connection between SCPV and SpeCo; SCPV must know the speed specified in SpeCo that will intervene in the process, know the IP address and the port through which it communicates. Upon knowing this information, SCPV implements the proposed control strategies and determines which segments are associated with SpeCo.

The configurations together with the proposed control strategy to be evaluated are captured in UTYiL format by SCPV, and this file is sent to CiudadelaSIM to perform the simulation requested. In the first instance SCPV, serves as a platform to obtain the modeling of the road infrastructure whose result is expressed in an UTYiL file, this platform was developed previously and presented in [10], it was integrated and modified for its correct operation. Finally, the three components are connected for a middleware that allows the communication between them.

4. ITSiE Architecture Modelling Framework: Case Study V2X

4.1 SpeCo Modelling Framework

The SpeCo is in charge of providing services according to a list of events (FEL) called *DecisionMaking*, which manipulates the behavior of the entities that are associated to an event within SpeCo that responds to the logic imposed by the requested service. An event of the type "DecisionMaking" can be modified by the user who wishes to verify different behaviors of certain entities within the scenario to be simulated.

For the present proposal, the association between the SpeCo and the traffic simulator CiudadelaSIM was raised through *DecisionMaking* type events. In this paper, the results of the performance of the SpeCo are presented within a road simulation network through the abstraction of the behavior of certain elements presented during the simulation.

Control policies are established, and parameters associated with the event sent by CiudadelaSIM are modified. In the case of this proposal, the DecisionMaking events are oriented to SpeCo based on V2X approach for speed control, where a set of parameters are defined, such as agents TL (traffic light) and V (vehicle), a maximum speed of the road, and the time of execution of the event. The speed is calculated based on the state of the traffic light and the time the vehicle is traveling and generates a change in speed to maintain a constant displacement.

The mechanism of operation of SpeCo begins when it receives a JSON (JavaScript Object Notation) data from CiudadelaSIM with the information of the vehicle to be controlled and the event associated to run; SpeCo determines the behavior in terms of speed through a DecisionMaking event and responds with new vehicle information. A new state and event encapsulated in JSON data.

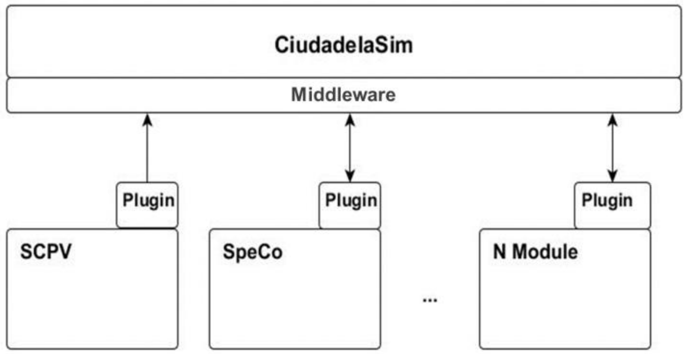

Fig. 4. General architecture of the integration of n components

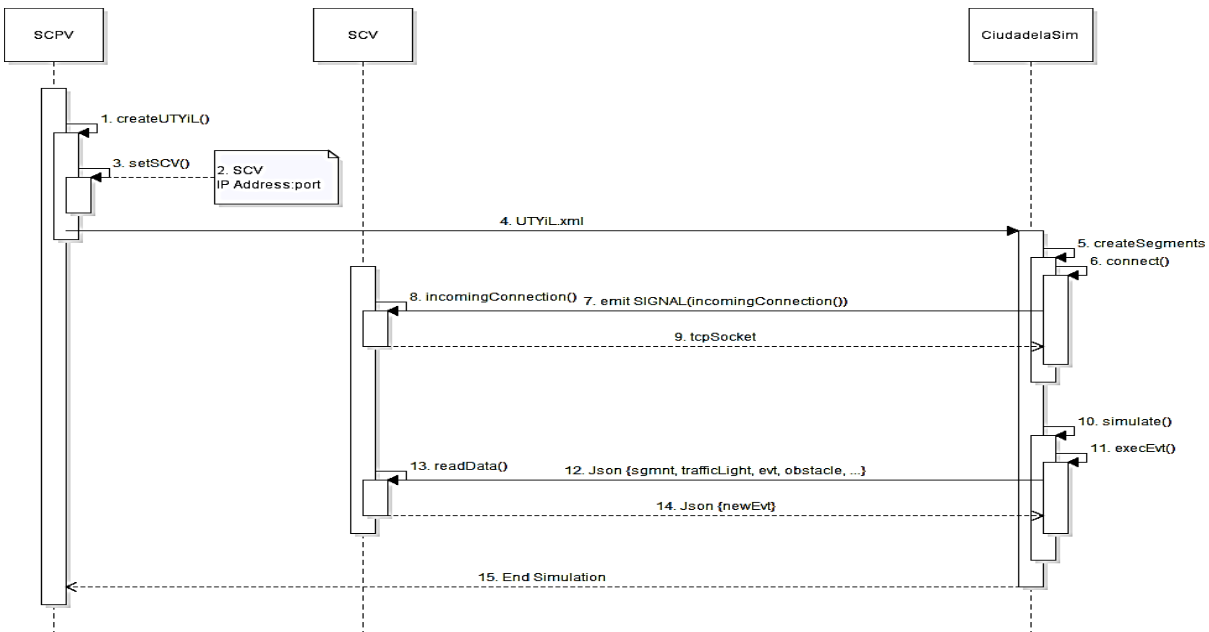

Fig. 5. Sequence diagram of the connection between SCPV, SCV and CiudadelaSIM

CiudadelaSIM receives the new event and continues with the simulation process. In addition to speed control, SpeCo allows us to evaluate, in conjunction with CiudadelaSIM, scenarios with problems that are more real-life like, such as accidents, distracted drivers, drivers with little road culture, among others.

4.2 Integrating V2X Elements in CiudadelaSIM

As mentioned before, the V2X technology is the communication between different elements inside a system. Each object within an urban traffic system communicates through a network with the other objects, vehicles as well as the urban infrastructure keeping updated about the current traffic situation [8].

Within the simulation machine, are the vehicle generator, whose function is to populate events of type AE to the FEL of segments of the Segment List and store the events in a database in PostgreSQL for the subsequent analysis.

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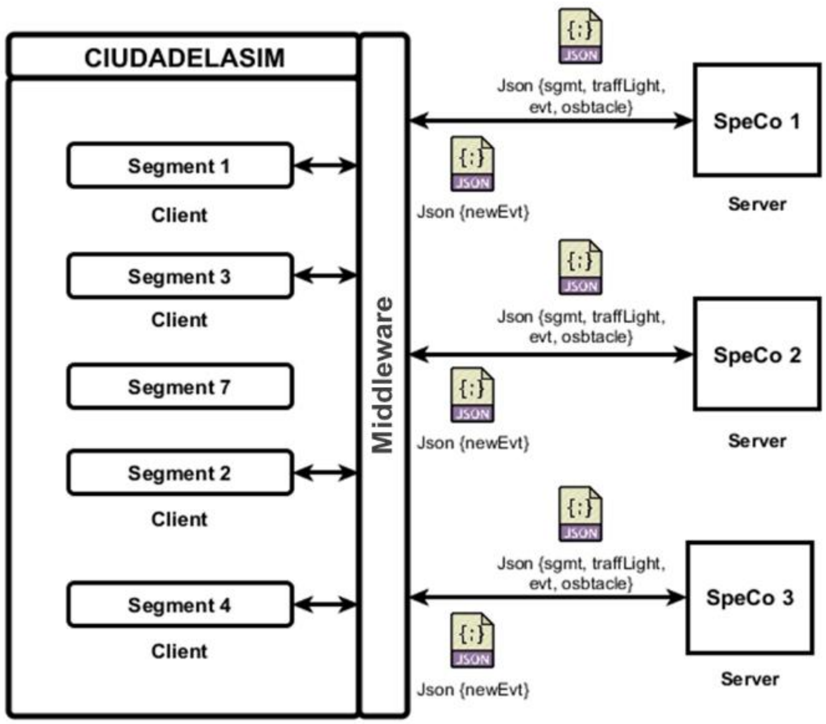

Fig. 6. Architecture multi-client, multi-server between CiudadelaSim and SpeCo

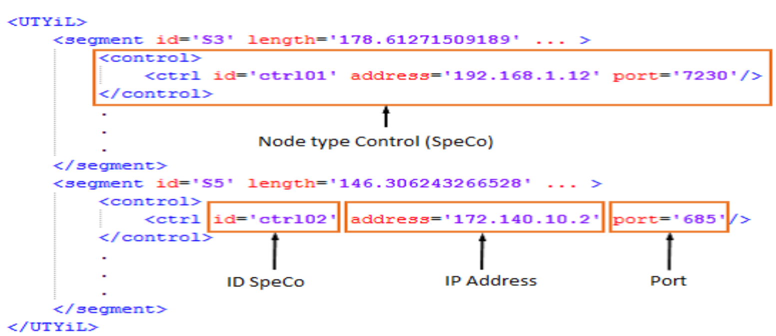

Fig. 7 Addition of the control node (SpeCo) to the UTYiL File

The visualization machine, to carry out the visual simulation of the UTYiL scenario (see Fig. 8), integrated the middleware to read the scenario and to be able to perform the visual simulation by consulting the events stored in PostgreSQL.

The integration of traffic control and evaluation tools in a simulation system is the first step to ensure that the reliability of urban traffic control provides a solution to current urban mobility problems or provide strategies to improve them. In order to validate the implementation of V2X technology, it becomes necessary to evaluate its performance in a simulated environment by providing a realistic simulation of stages where V2X technologies are in contact with a network of urban traffic.

The Fig.4 shows a general block integration diagram, where the development of middleware was necessary and whose function is to integrate SCPV and SpeCo components to the traffic simulator CiudadelaSIM through the middleware. In addition, modularity is allowed for the integration of *n* components, through the middleware and a plugin connection.CiudadelaSIM is the main component of ITSiE, all components are connected through a middleware. Where a JSON-type data is sent for each execution of an event with a set of parameters associated with the event and SpeCo responds with a JSON-type data with a new event based on the analysis of the sent parameters.

To describe the process and connection activities between urban traffic modeling and evaluation tools: CiudadelaSIM, SpeCo, and SCPV, a sequence diagram is presented in Fig. 5.

The process starts when SCPV creates a new UTYiL file of configurations for the capture of road proposals (SCPV) which receives an IP address manually (that is, set by the user) and the port through which the SpeCo connects. SCPV determines within its graphic interface which segments are under the control of a given SpeCo. The next step is the submission of the simulation proposal in the UTYiL language to CiudadelaSIM, who immediately loads the simulation proposal and sends a connection request through a socket to the SpeCo based on the configuration received in the UTYiL file, giving the control of a segment and the respective elements that make up the SpeCo.

The simulation takes place inside CiudadelaSIM. During the simulation, each time an event appears within a segment under control, it sends a request to SpeCo with a series of attributes corresponding to the object related to the event to be executed (vehicle or traffic light) and SpeCo responds according to the logic focused on speed control. At the end of the simulation, SPCV accesses the data stored in a database by CiudadelaSIM for further analysis.

Under this scheme, a client-server model is presented, in which CiudadelaSIM takes on the role of the client and the SpeCo as a server. Each time an event is simulated in CiudadelaSIM that requires executing a decision-making process, CiudadelaSIM will consume the service corresponding to the event that is running within the SpeCo with the JSON-type data in the format of sending messages to consume its services.

Fig.6 shows the ability of SpeCo to host multiple clients in a parallel way having control of one or more segments within CiudadelaSIM, this makes CiudadelaSIM a multi-client that simultaneously connects with multiple servers.

4.3 Implementation of V2X Elements in ITSiE

As previously mentioned, the UTYiL language is a language where the configurations of the vehicular traffic control proposals are captured through the interface provided by SCPV and SpeCo is integrated so that it interacts directly with CiudadelaSim. The process of integrating SpeCo to SCPV is done manually, where the SCPV user must know the physical address, the port and assign an ID to the segments that require control of the SpeCo within the SCPV platform.

Fig. 7 shows the modification of the UTYiL file when the "segment" element and the information related to the SpeCo is added. The "control" element in the segment is added to the UTYiL file. Inside the "control" element is the element "ctrl" that contains the parameters of the SpeCo previously determined by the user. Below are the parameters that comprise it.

Once the modification of the UTYiL file has been described, SCPV sends the simulation proposal to CiudadelaSIM; CiudadelaSIM receives and interprets the configurations described in the file. The connection between CiudadelaSIM and SpeCo is carried out through a web service through sockets with the communication of the TCP / IP protocol.

5 Results

For the following scenario called *UTYiL3-129*, the microscopic simulation of a region with four segments and an intersection was tested (see Fig. 8), which is composed of two traffic lights to coordinate the vehicular flow and two sources traffic. In the first view, the simulation was carried out without using the SpeCo, while in the second view the SpeCo was integrated with the purpose of performing an analysis of the behavior of the vehicular flow and the density with and without it. Fig. 9 presents the same scenario with more details.

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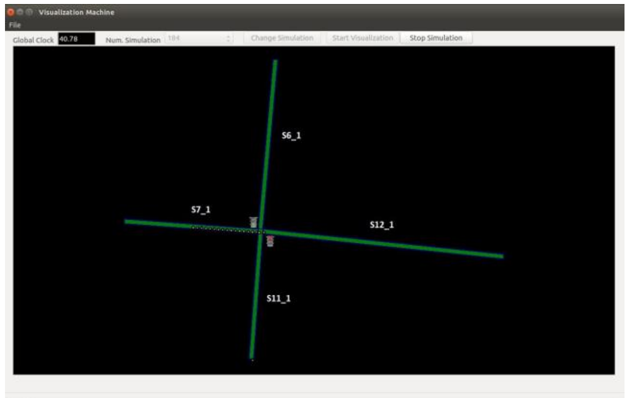

Fig. 8. Scenario created by UTYiL and visualized since the visualization machine in CiudadelaSIM

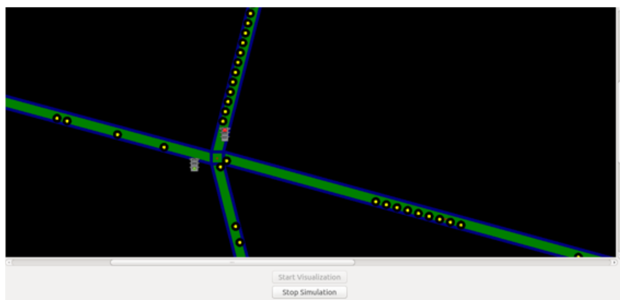

Fig. 9. Scenario created by UTYiL with zoom

Table 1. Traffic light Times

IDSEGMENT	IDOBJECT	START(SEC)	END(SEC)	TIME TO STATE 3 (GREEN)	TIME TO STATE 2 (YELLOW)	TIME TO STATE 1 (RED)
S7_1	SE7_1	0	350	30	10	40 (START)
S11_1	SE11_1	0	350	30(START)	10	40

Table 2. Vehicular Capacity

IDSEGMENT	TRAFFIC FLOW (VEH)	FLOW TRAFFIC (SEC)	ROUTE
S7_1	20	80	I7_1,S6_1
S11_1	20	80	I7_1,S12_1

In both views, 1) with speed control and 2) without speed control; the configurations of the traffic lights described in Table II and Table III the vehicular capacity is the same.

Table II shows the duration time of each light state (1. *red* to stop, 2. *yellow* to notice the traffic light is changing to red, and 3. *green* to move), the segment to which the traffic light time object is associated, the operating time and the initial light state.

Table III describes the specifications for every segment, the traffic flow, time of duration and the route specified.

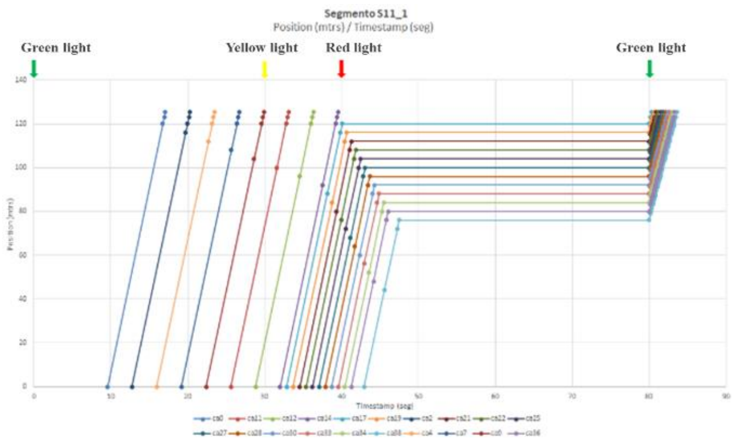

Fig. 10. Analysis displacement of the segment S11_1 without the SpeCo in the scenario UTYiL3-129

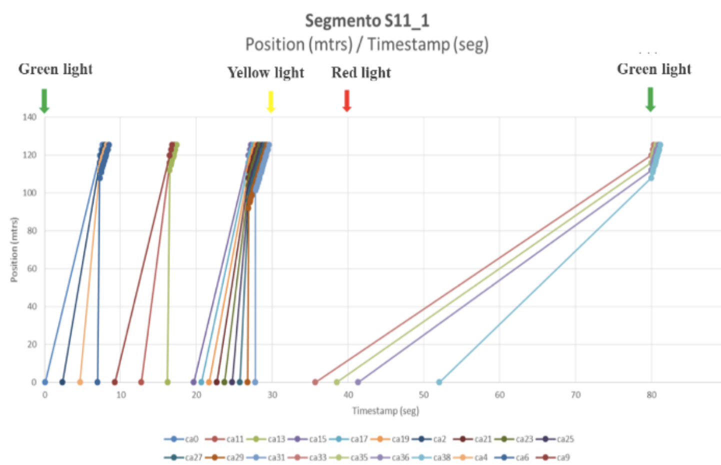

Fig. 11. Analysis displacement of the segment S11_1 using the SpeCo in the scenario UTYiL3-129

In order to understand the scenario, the description of the actions is concentrated in two segments, S7_1 and the S11_1.

In the segment S7_1, the initial light state is red, while the segment S11_1 starts in the green light state corresponding to the generation of the vehicle, the configurations shown in Table III were taken as reference, segment S7_1 and S11_1 have 20 vehicles generated over a period of 80 seconds.

According to the route of displacement of each vehicle generation source, it was established that segment S7_1 will travel to intersection I7_1 and end its route in segment S6_1; while segment S11_1 will travel to intersection I7_1 and end its journey in segment S12_1.

5.1 Case study UTYiL3-129

As a result of the simulation of the UTYiL3-129 scenario (with and without the SpeCo), displacement graphs of the vehicular flow were obtained. For the validation of the interaction between SpeCo and CiudadelaSIM, the behavior of the vehicle capacity within segment S11_1 was analyzed.

a) Scenario without SpeCo

Fig. 10. represents the displacement of vehicular traffic without the integration of the SpeCo; the results show a constant speed in the vehicles based on the inclination of the displacement of each one, except when the traffic light status is red; in this state, the vehicle maintains its position and the speed is reduced to 0, triggering a green wave effect when the traffic light changes to green giving way to the flow of queued vehicles.

b) Scenario with SpeCo

On the other hand, Fig. 11 shows the displacement of vehicular traffic by integrating the speed control (SpeCo), where a change in the behavior of the vehicles can be observed; reflecting a variation in the speed of each vehicle in the inclination corresponding to the displacement, avoiding entering a stopped state when the traffic light is red.

Within the simulation, the communication between the various entities involved in the traffic system was carried out by sharing information about the state in which they were. Fig. 11 shows a successful interaction between vehicular agents (vehicles) and traffic control (traffic lights), as a result of the change of speeds in the vehicles.

With these results, we can appreciate the integration of the three components in the architecture. It is possible to develop an architecture broad enough to integrate two or more systems of modeling and control of vehicular traffic that incorporates physical-cybernetic elements in a simulated environment.

6 Conclusions

A modeling architecture using the V2X technology in virtualized environments is presented using the microsimulation based on multi-agent systems oriented to events. Three components are integrated for the control and modeling of urban traffic, showing its viability. CiudadelaSIM is a tool that allows to evaluate the integration of new road elements to proposals and observe the behavior during a determined time. SCPV is the component that allows making proposals of scenarios with different traffic elements and SpeCo allows to control the speed of a vehicle on a controlled environment.

The purpose of this architecture is to observe the behavior of different vehicular conditions and to propose functional strategies to improve urban conditions before to be implemented in real life. These results allow to expand the decision making for improving road situations in any section or segment of streets through the evaluation of road proposals. In addition to being an open source and modular architecture. In this proposal, the integration of the TCPS in a simulated environment was carried out using the CiudadelaSIM, SCPV and SpeCo components.

The development of the platform created for the evaluation and simulation of traffic in real environments has made it possible to analyze and improve the results obtained in a satisfactory manner. The architecture proposed permits to validate the connection and verification of how simulations are achieved under controlled and intelligently controlled environments.

The architecture described throughout this paper made it possible to implement an approach to the integration of TCPS in a simulated environment called CiudadelaSIM that integrates physical elements to associate and simulate any modification of the behavior of vehicles, so that decisions can be made at events by controlling speeds within the simulation.

The proposed architecture showed that it can be used in a modular way, as well as being multi-platform and multi-language by integrating new systems adapted to the behaviors emitted by the vehicles through the development of a plug-in connection with the CiudadelaSIM simulator.

In this work, a formalism was defined for the discussion of the generic TCPS modeling concepts used in the integration of systems through the proposed Simulator CiudadelaSim as the main element of the architecture ITSiE. In addition, CiudadelaSIM was evaluated as a component that helps to compare variants regarding the analysis of vehicular traffic such as density, vehicle flow, and speed of each vehicle, and a model that can be used for future research in the design of TCPS.

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