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MOVEMENT CONTROL OF A VEHICLE FLEET

BY

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Abstract. This paper synthesizes the main contributions published in major scientific works regarding the movement control of groups of vehicles. Control is carried out based on a set of inter-vehicular communications (IVC) protocols and applications. IVC protocols have the potential to increase the efficiency and comfort of transportation systems that involve airplanes, trains, motor cars and robots. Applications fall under four classes with common organization systems in terms of communications and similar performance requirements. Vanet Cluster Simulator (VCS) is a traffic simulator which allows viewing the number of clusters the target vehicle is part of. The authors used it to simulate a traffic situation using an existent map.

Key words: inter-vehicular communications (IVC); IVC protocol; IVC applications.

1. Introduction

Increasing the safety and efficiency of smart systems that can be applied to vehicles, robots or aircrafts programmed to move in formation can be achieved by means of information exchange between vehicles on a neighbor-to-neighbor basis. Communication between vehicles that does not rely on a preinstalled infrastructure can be carried out by implementing ad-hoc mobile networks (VANET), where vehicles act as communication nodes with ever-

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changing topologies (Bogdan, 2006). Communication can also be enabled by a specially implemented fixed infrastructure or by general communications systems, such as cellular or Ethernet based ones. Vehicles can act as information sources, they can relay information or broadcast information to other vehicles within the network. The type of information depends on the application that is used and ranges from data regarding the movement of the vehicle to multimedia data or internet content. Communication can be either "one-to-one" (between two vehicles), "one-to-many" (between the leader of a group and the members of the group of vehicles), or "many-to-many" (between vehicles that are geographically close to each other and that communicate their relative positions in order to avoid collisions).

2. Implementations of IVC Protocols

An example of IVC application is presented in Fig. 1. In this application, the leading vehicle (the leader) sets the rhythm and communicates the maneuvers to the vehicles that follow its lead. Each vehicle aims to maintain a constant distance from the vehicle in front of it (Gandahi *et al.*, 2015), and to this end it calculates the relative distance, speed and acceleration of the preceding vehicle, using these data for the "closed loop" control of its own speed in order to reduce the distance error. The leader sends its movement data to the other vehicles in the column formation, which use them as reference data in order to avoid the propagation of distance errors along the column (Arkian *et al.*, 2015). The column leader can send out control messages in order to reorganize the group or to announce route changes (Rawat *et al.*, 2011).

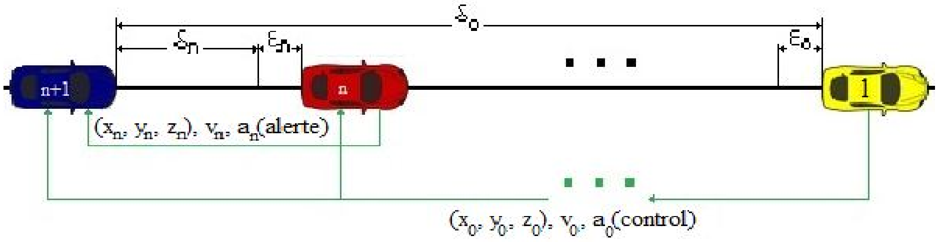

Fig.1. Column formation of vehicles using data broadcast by a leader in order to maintain a mandatory distance δ between the vehicles.

The requirements of applications together with the basic requirements of VANET networks determine how an IVC protocol is defined. Some applications require that messages reach the vehicles within a minimum time frame and at a particular level of reliability, and the protocol has to ensure their reception by all the road users by means of effective information dissemination, packet loss detection, and techniques for the recovery of lost packets, (Satyajeet *et al.*, 2016). The number of vehicles and the distance to these vehicles largely influence the architecture of the communication protocol.

The IVC protocol is vulnerable to false data injection attacks, data corruption and jamming. Blocking attacks is the objective of a Road Traffic Safety Consortium (Car-to-Car Communication Consortium). In some implementations, IVC protocols can make connections with other types of networks by means of cellular base stations or wireless access points. For instance, a message that is meant to reach all the vehicles in a group can be relayed using fixed relays located at each intersection. An IVC network that is not delay-sensitive can temporarily store notices regarding traffic conditions for subsequent distribution purposes (Papadimitratos *et al.*, 2008). In order to convey messages to the users, the system may include charts with individual or group addresses of the vehicles. The vehicles can be provided with infrared, sonic or proximity sensors and with computation systems that process communication data, execute IVC applications and operate system control, issuing warnings.

3. Types of IVC Applications

Fig. 2 provides a complete list of inter-vehicular communications applications, which fall into four types (classes).

Type 1 applications are designed for vehicles fitted with GPS modules and a wireless transceiver and which use a data base for storing encounters with other vehicles). Each vehicle queries the data bases of the VANET members, using targeted messages and can locate other vehicles by tracking road traffic values (Schitiu *et al.*, 2008).

The **type 2** group comprises safety applications that are more sensitive to transmission delays than to traffic throughput. Delay tolerance increases with the distance between the source and receiver due to the interactive nature of these applications. They are part of the vehicle-infrastructure communication system, where emergency warning messages are broadcast via VANET in order to detect the location and movement status (e.g.: acceleration and speed) of vehicles, indicating abnormal situations, such as accidents, mechanical failures, bad weather conditions, etc. It is presumed that vehicles are fitted with GPS modules and short-range wireless communication equipment. A typical example of type 2 application is the CarTALK 2000 Project, which also includes a warning function as part of the driver support system. In this system, emergency messages are sent throughout a particular geographical area using multi-hop connections in order to warn other drivers with respect to accidents, traffic anomalies and dangerous parts of the road (Uchim *et al.*, 2009). The application requires a message processing and delivery delay below 40 ms and a message repeating frequency higher than 50 Hz.

The **type 3** group comprises applications that can use IVC transmissions in order to change the position, speed, acceleration and direction of movement (Krishnamurthy, 2009). If message latency is not low enough, this information can be used to control motor vehicle acceleration and breaking operation or to generate a collision warning or a collision avoidance plan. No action is carried out to coordinate the group's movement. Vehicles simply control themselves using information collected from their neighbors (Schrank *et al.*, 2009). The interaction between neighbor vehicles is usually extremely short, lasting no more than a few seconds or minutes. Vehicles use GPS modules and digital maps in order to locate intersections.

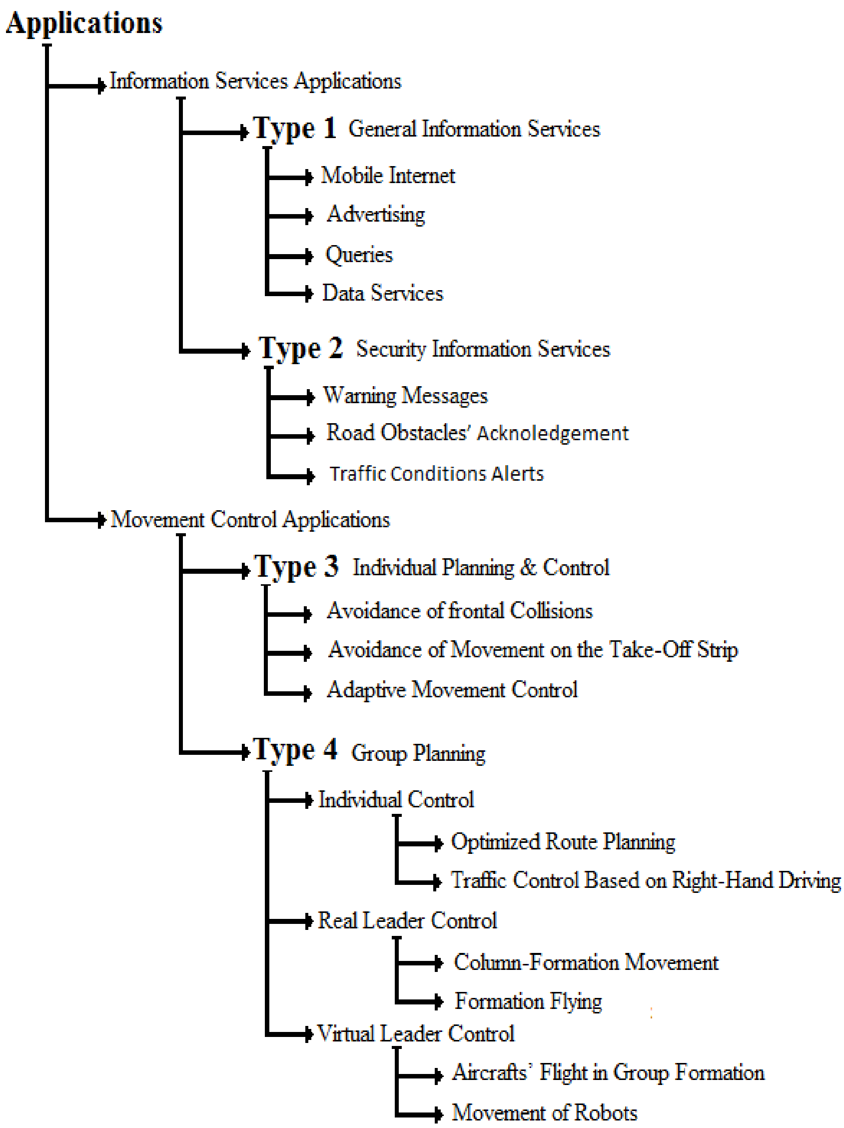

Fig. 2 – Types of IVC applications.

When they are 50 m away from an intersection, vehicles broadcast their location, movement direction and speed, thus enabling the other road users to undertake collision avoidance maneuvers (Thangavelu *et al.*, 2009). Inter-vehicular communications are used for avoiding collision with the vehicle in front. Laser, radar or sonar type sensors can provide more information for the preceding and next vehicles.

The **type 4** group comprises applications where vehicles have the same mission or the same destination (Jawhar *et al.*, 2010). In these applications, vehicles are generally organized in groups for the purpose of streamlining complementary routes' planning and joint transit. Vehicles stay within the same group for a long period of time (*e.g.*: minutes, hours, days). To ensure a coherent interaction, vehicles need to exchange control and status information with a higher degree of certainty (Nekovee, 2008). Several movement control architectures are considered for planning purposes, architectures that require a low latency of the position data exchange with the real or virtual leader. Data exchange between vehicles that move together is carried out in a coherent manner. Movement can be complex, while congestion or certain maneuvers can involve only a part or the entire group of vehicles. Type 4 applications avoid collisions in intersections by mandating vehicles to ask for and obtain the right (based on receiving a token) to enter the intersection. Such mechanisms can replace conventional traffic control, providing a higher level of security. If vehicles or vehicle column formations receive a token before entering an intersection, they shall return it when leaving the intersection. The vehicles must adhere to a group as they draw closer to the intersection and are located in "waiting lines" that monitor and disseminate the data for the purpose of determining the rate of occupation of the intersection and the right-hand driving mode, (Lambert *et al.*, 2010).

4. Planning the Movement of a Group of Vehicles

IVC protocols can be used for the global optimization of route planning for vehicles that meet each other but do not necessarily use the same route or share the same destination. Vehicles individually regulate their movement, adjusting their speed and trajectory according to the other neighbors. Vehicles set their route alternatives in a coordinated manner (Tang *et al.*, 2010). The application requires message processing and delivery delays below 100 ms, a message repeating frequency higher than 50 Hz and a reliable connection.

5. Leader-Based Movement Control of a Group

In leader-based control, one of the vehicles in a group broadcasts the movement reference and controls the group. Each vehicle belonging to the group combines the information received from the leader with the information about the movement of their neighbors in order to set their own acceleration or deceleration. Each vehicle uses the relative spacing advertised by both the preceding vehicle and the leader so as to regulate the movement of the column formation. All the vehicles must store in a buffer all the movement-related data they receive and update the control data (Taleb *et al.*, 2010). The maximum spacing and speed errors are determined by the longest delay within the group, thus emphasizing the need to deliver packages with minimum latency data.

In real vehicle systems, leading can be much more complex and it involves more responsibility. The leaders can coordinate the inclusion, relinquishment and execution of maneuvers by the group members. Such actions require regular and reliable communications between and within column formations. The AHS system describes these responsibilities in the context of a complex traffic system that uses both of the communication systems: vehicle-infrastructure and inter-vehicular ones, respectively. The leaders of column formations talk to each other in order to agree when and in what order to use the intersection (Felice *et al.*, 2012). Leadership can thus be improved using the concept of “team work”, whereby the vehicles in the column formation receive a secondary function in the execution of tasks, functions such as “space creator” or “safety observer”.

6. Virtual Leader-Based Movement Control of a Group

In order to coordinate the movement, vehicles have to communicate common directions to each other. These must be sent out by a leader vehicle or established by the vehicles using a consensual process. The latter approach is called a virtual leader model. Virtual leader model type applications use communications of the “many-to-many” type. IVC protocols allow the execution of complex maneuvers, such as grouping with maintenance of a safety distance between vehicles (Farooq *et al.*, 2012). Vehicles use IVC to update a common state space with their movement data and perform a calculation of the weighted average of the other road users’ data in order to determine their trajectory during the next step.

7. VANET Cluster Simulator

VANET Cluster Simulator (VCS) is a traffic simulator which allows viewing the number of clusters the target vehicle is part of. To initiate a simulation open VCS and load a existent map or create a new one (Fig. 3).

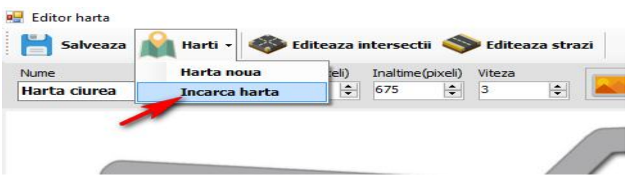

Fig. 3 – Map editor.

It adds new cars pressing the button “***Masini***”. The editor will be open. Select the color, the angle, than press “***Adauga masina***”. For modifying the position and point of destination, the car it must be selected on the map. The selected car will choose itself the shortest way to the destination (Fig. 4).

Fig. 4 – Add new car.

The start points will be chosen pressing "***Marcheaza start***" (Fig. 5).

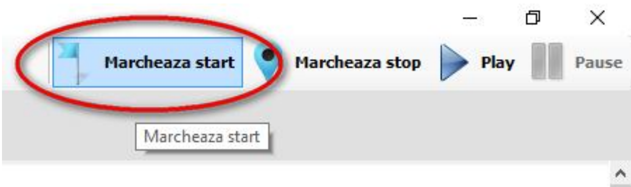

Fig. 5 – Mark start.

Than select the map belonging the start point. This way the start point will be pointed with a blue flag (Fig. 6).

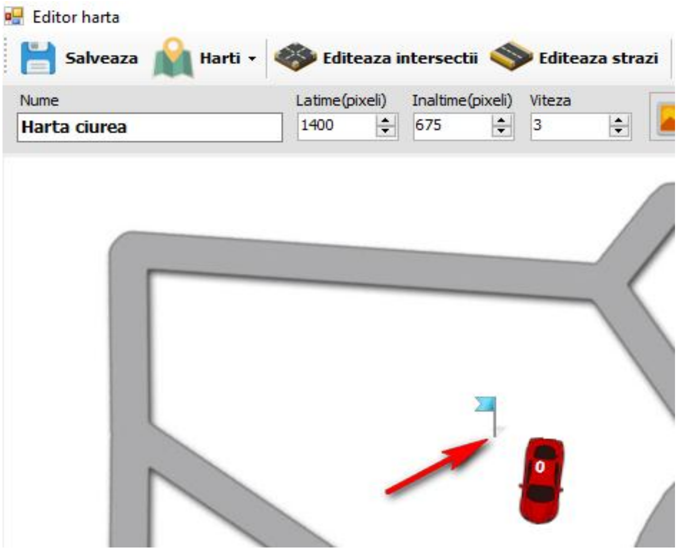

Fig. 6 – Blue flag on map.

Repeat the algorithm for the destination point (Figs. 7 and 8).

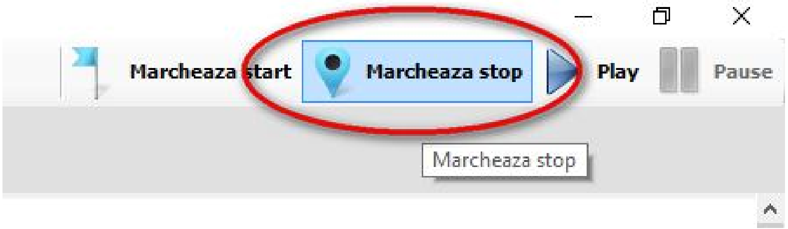

Fig. 7 – Mark stop

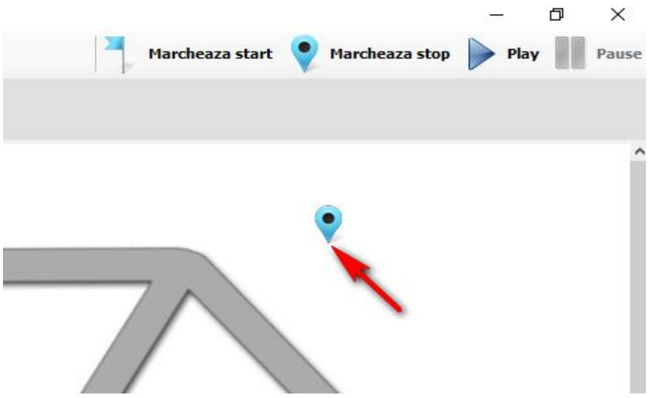

Fig. 8 – Blue drop on map.

To start the animation press "***Play***" (Fig. 9).

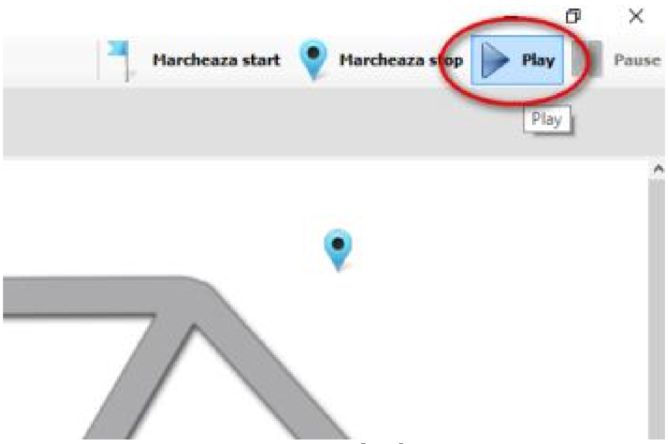

Fig. 9 – Press play button.

Inside the window Editor masini, the neighbors and the detected clusters for the selected car can be observed (Fig. 10).

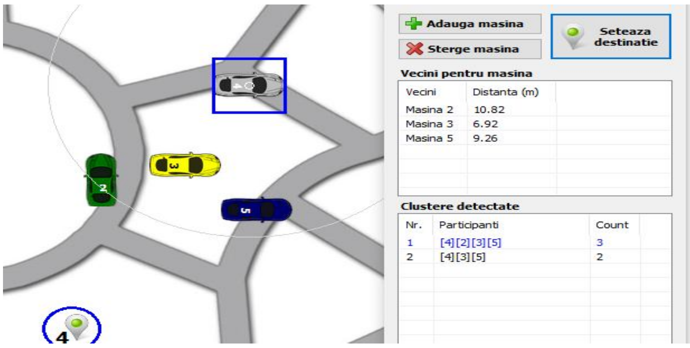

Fig. 10 – View clusters.

8. Conclusions

The original motivation of ad-hoc vehicular networks (VANET) was to a promote traffic safety, the importance and potential impact of which were confirmed by several initiatives supported by motor vehicle manufacturers, various governmental agencies, as well as by the academia. There are significant prospects for developing applications based on the association of IVC protocols with mapping schemes or token-based intersections (*e.g.*: ASDM, LCA, V-PEACE or WTRP protocols that reserve resources of the communication channel for each vehicle within the network). VANET has its unique features for the space and time location of a dynamic group of vehicles. IVC protocols can be used for the global optimization of route planning for vehicles that meet each other but do not necessarily share the same route or the same destination.

VANET Cluster Simulator in communications will effectively improve the safety, capacity and comfort of multi-vehicle systems once the traditional impediments to their adoption, such as the cost of infrastructure and degree of complexity, are minimized.

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CONTROLUL DEPLASĂRII UNEI FLOTILE DE VEHICULE

(Rezumat)

Se prezintă o sinteză a principalelor contribuții publicate în lucrări științifice reprezentative privind controlul deplasării grupurilor de vehicule. Controlul se realizează pe baza unui set de protocoale şi aplicații de comunicații intervehiculare (IVC). Protocoalele IVC au potențialul de a creşte eficiența şi confortul în sistemele de transport implicând avioane, trenuri, automobile şi roboți. Aplicațiile sunt clasificate în patru clase ce au organizări comune de comunicații şi cerințe similare de performanță. VANET Cluster Simulator (VCS) este un simulator de trafic care permite vizualizarea numărului de clustere din care face parte un vehicul țintă. Autorii au utilizat VANET Cluster Simulator pentru a simula o situație de trafic, utilizând o hartă existentă.