Investigating the Efficiency of ITS Cooperative Systems for a Better Use of Urban Transport Infrastructures: The iTETRIS Simulation Platform

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Abstract— **The use of cooperative ITS communication systems, supporting driving through the dynamic exchange of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) messages, is a potential candidate to improve the economical and societal welfare. The application of such systems for novel cooperative traffic management strategies can introduce a lot of beneficial effects not only for road safety, but also for the economy related to transportation systems and the environmental impact. Despite this apparent set of promising features, City Road Authorities, which hold a key-role in determining the final adoption of such systems, still look at cooperative systems without sharing a clear opinion. This is mainly due to the current lack of definitive and solid evidences of the effectiveness of such systems when applied in the real world. In order to fill this gap and let Road Authorities estimate the usefulness of such technologies in achieving the objectives dictated by cities' traffic management policies, the EU consortium iTETRIS is developing a simulation platform for large scale testing of traffic management solutions making use of cooperative ITS systems. Thanks to its own distinguishing features, iTETRIS aims at becoming a good supporting tool for Road Authorities to implement preliminary tests on the effectiveness of ITS solutions prior to investing money for the physical deployment of the communication infrastructures allowing their functioning.**

I. Cooperative ITS Systems: Reasons, Definition and Potential

Road mobility influences the society under various aspects. The close relationship between more efficient transport and the economic growth is only a first evidence of this statement [1]. If a deeper look at this topic is given, one can realize that an increasing demand for movement over roads and car utilization has constantly occurred over the last 40 years, in terms of both private and freight transportation [2]. As a consequence of this, many effects are visible in our everyday life. Current road network are in fact experiencing a saturation which is not only affecting the societal safety by a higher number of fatalities, but also the economical productivity, the energy consumption and the environment impact. In fact, according to [3], the number of accidents yearly occurring in the European Union implies costs representing percentages of the EU GDP which are not negligible. Also, the energy employed in the EU for road transport has been assessed over the last years to represent more than one fourth of the total consumption, resulting in very high CO_2 emissions which by far constitute the majority of the total transport emissions.

Looking at these values and considering the general increasing trends of the road transportation demands, it is clear that a solution to these issues has to be found. A particular attention is needed if the case of the urban areas is considered. Here, the impossibility to cope with the road utilization saturation by building additional infrastructure imposes new challenges. Anyways, unused capacity to serve the traffic demand already resides in existing urban road infrastructure and has been estimated to constitute an additional percentage of around 20-30% [4]. In this context, new traffic management strategies based on the use of novel cooperative ITS (Intelligent Transportation System) solutions find their field of applicability.

Cooperative ITS solutions are often referred to as V2X systems. They base their functioning on the adoption of wireless communication between cars (V2V or Vehicle to Vehicle communication), or between cars and infrastructure radio stations (V2I or Vehicle to Infrastructure communication). For these solutions to be fully functioning and effective, vehicles are required to be equipped with the radio communication systems allowing them to interact in real time with the local environment. Exactly in the same way, the road network has to be completed by fixed infrastructure stations giving it communication capabilities. Being wired connected to a backbone communication network and via radio to vehicles, these fixed radio stations can constitute the link allowing the information exchange between cars and the management centers in charge of monitoring and administrating the traffic situation. Allowing cars to communicate with each other and providing them with the possibility to interact with the road communication infrastructure and the traffic management centers permit the realization of several new road safety and traffic management solutions. For example, dangerous or anomalous situations such as accidents or road traffic congestions may be rapidly detected, effectively notified and quickly solved or mitigated. Such possibilities are depicted in Figure 1. In situation a), thanks to on board sensors (e.g. detecting the activation of airbags), two vehicles colliding at an intersection are able to autonomously detect this event. As it is evident, if no rapid countermeasure was taken, all the road segments being afferent to the intersection would experience traffic jams blocking the circulation. However, through the use of radio capabilities, the vehicles involved in the collision are able to warn the surrounding environment as soon as the accident

occurs. A notification message starts to get propagated over the incoming vehicles that, after processing the message, retransmit it towards the peripheral parts of the illustrated scenario. Here, vehicles receiving the notification are not only able to be quickly warned, but also to avoid the congested zone by taking alternative routes. In situation b), the temporary presence of road works is currently causing a slowdown in the traffic flow. By exchanging and processing radio messages, the vehicles involved in the congested zone can run algorithms to realize that such a situation differs from the normality, and that a reaction has to be undertaken in order not to further congest the area. A notification message is thereby generated and delivered through the incoming vehicles, which, as in the previous case, can select alternative directions.
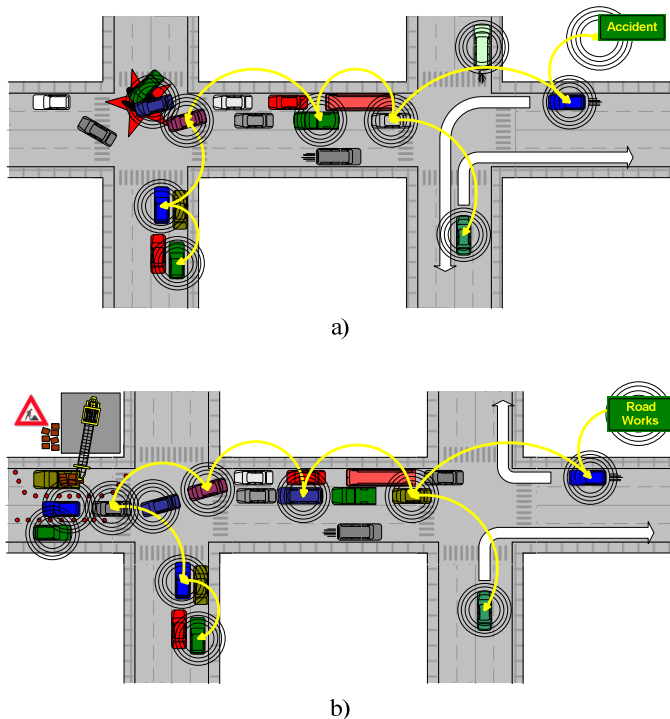

a)

b)

Figure 1: Examples of cooperative ITS systems' utilization. a) Accident occurrence notification; b) Traffic congestion detection and dissemination

It has to be highlighted that, although not shown in the examples, these procedures can be supported by the already mentioned fixed radio stations eventually deployed in the considered scenario. In both situations a) and b), the presence of fixed radio stations can activate a link between vehicles and traffic centers, so that traffic situations can be monitored in a centralized fashion. In this way, the decisions about where to disseminate radio notifications of anomalous events are taken from the traffic center's wider perspective and therefore are more rational. After selecting the zones where the notifications are needed, the traffic center uses the available fixed communication infrastructure stations to transmit the messages over them. By following similar approaches, the deployment of novel, dynamic and intelligent traffic management applications is possible. The introduction of ICT technologies

into cars will convert them into active mobile probe sensors increasing not only their capability to quickly detect and notify dangerous situations, but also the accuracy and the reactivity of current solutions used to estimate the traffic conditions, like for example inductive loops. As shown, effective vehicle rerouting policies or other kinds of traffic reactions may be generated and communicated anywhere over the road network in a very straightforward way. All this allows improving the mobility under the various aspects previously mentioned: reducing dangerous situations, traffic congestions and travel times with consequent beneficial repercussions on safety, economy and environment.

The European Union has already been promoting for years the research on the feasibility and effectiveness of such solutions [5]. At the same time, big efforts have been done by the industrial and academic world to create and develop the suitable technology allowing inter-vehicular communications. Moreover, standardization entities like the European ETSI are currently working to settle agreed communication architectures regulating V2X systems' use and exploitation. However, the final success and the definitive application of these systems is mainly dependant by the user entities devoted to finally implement and exploit the cooperative system technology: the City Road Authorities. Although cooperative ITS systems seem to be a very promising solution for a more rational use of urban road infrastructure, City Road Authorities look at them with a certain skepticism. The main reason of this is that the effectiveness of such systems cannot be proven before a full deployment, whose cost would require relevant investments [6]. In fact, before City Road Authorities can fully embrace such technologies, there is a need to present them with solid and conclusive evidence clearly showing the performance of cooperative ITS solutions and showing how results are achievable which fulfill cities' desired objectives and overlap with the goals they aim at. This issue is mainly due to the current lack of means for accurately evaluating whether the contribution of V2X in supporting innovative traffic management strategies is good enough to justify the costs of their implementation.

II. THE iTETRIS CONCEPT

To provide an answer to the aforementioned issues, the iTETRIS research project (www.ict-itetris.eu) has been financed by the EU FP7 programme. iTETRIS is devoted to the development of a European open source integrated platform for combined traffic and communication simulation. The other research initiatives which have been so far financed to investigate the functioning of cooperative systems often assume the use of small-sized real world experiments. Even if these tests can quantify the correctness of vehicular on-board technologies' implementation in a more realistic way, they present intrinsic critical limitations preventing them to generate exhaustive conclusions about the real impact and usefulness of such systems. These limitations are a consequence of the practical impossibility to convert such tests into long-lived experiments involving large areas and high number of vehicles. When evaluating traffic management

strategies, such estimates become a key point since traffic strategies may concern decisions that, adopted in a given location, may affect road traffic conditions in other ones. iTETRIS peculiarity compared to other research projects or simulation platforms lies in the fact that it is being engineered to efficiently evaluate Cooperative ITS traffic management strategies over such large scale scenarios [7]. With these characteristics, iTETRIS is presented as a valid supporting tool for City Road Authorities to get a first insight of the potential of cooperative systems. As the final users of such technologies, Road Authorities can select among the various capabilities offered by cooperative systems those for implementing the traffic strategies to fulfill their own goals. Under these conditions, iTETRIS provides a complete simulation tool where a first evaluation study of effectiveness can be conduced before investing on the physical deployment of the V2X technologies needed. As stated above, the reliability of iTETRIS results derives from the possibility of running simulations involving metropolitan areas, long times and a high number of vehicles. On the other hand, if it is assumed that a given city already presents cooperative ITS system availability, the tool can be used for optimization policies. Maintaining and modifying currently adopted strategies or implementing new ones to manage traffic in a more efficient way will be possible through the use of iTETRIS. As a simulation platform, it can be used to find and evaluate solutions for more rational (or less impacting) car traffic flows. This will in turn result in a lot advantages, e.g. a more efficient usage of the road infrastructure, a more comfortable mobility for pedestrians and goods, an easier local freight transport and a lower environmental impact. iTETRIS can also help to investigate the impact that public and private transport have on each other: policies for promoting the public transport or bounding the normal car access over certain areas can be simulated and their consequences can be studied. Finally, iTETRIS can evaluate the capability of V2X systems to actively collect traffic data and realize more accurate and real time traffic monitoring: traffic management centers would be constantly fed with up-to-date information reflecting the real underlying status of traffic situations; traffic jams or road fatalities would be suddenly detected and their negative consequences mitigated in a very real time fashion; traffic lights timing configuration procedures could more efficiently follow the changes in the traffic demand (e.g. increasing of traffic volumes in rainy periods). Also, the use of cooperative systems as valid replacement of traditional methods for traffic monitoring (e.g. inductive loops) could be assessed (please see next section).

III. PLATFORM, STRATEGIES AND SCENARIOS

As mentioned in the previous section, the aim of the iTETRIS project is to realize a *European standard compliant, sustainable and open source platform combining traffic mobility and wireless communications simulation abilities to investigate the use of V2X technologies in cooperative traffic management strategies over large-scale scenarios*. Its capacity to investigate the reactions that V2X exchange of messages imply on vehicles' routes permits to generate reliable, accurate and multidimensional results to fully examine the potential of cooperative systems. To achieve all this, a 3-blocks architecture is adopted (see figure 2). SUMO and ns-3 are two open source simulation platforms, respectively for traffic mobility and wireless communication, which are integrated by a third block called iTETRIS Control System (iCS). Application algorithms supporting cooperative traffic management strategies are independently implementable out of the platform, on the top of the iCS.
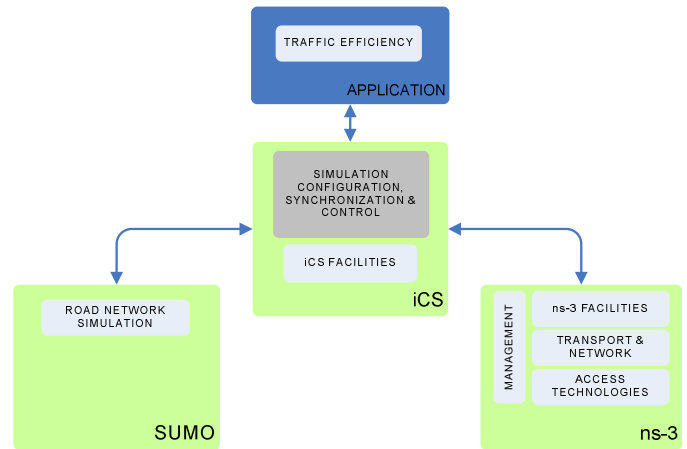

Figure 2: iTETRIS platform structure

The functioning of iTETRIS is an interaction between its blocks. Triggered by Application commands, ns-3 simulates V2X radio communications in vehicular scenarios. When the wireless simulator generates receptions deriving from these communication sessions, it notifies these events to the Application block, which, in consequence, imposes actions to vehicles or other objects (e.g. traffic lights) in the road network simulated over SUMO. As a result of this, SUMO continuously feeds the other blocks with vehicles' position updates, whose knowledge is essential for wireless simulations. As the central module in the architecture, the iCS facilitates the exchange of data between all the functional blocks and supports the simulation flow by control and synchronization functions.

iTETRIS identifies and defines a set of practical solutions (called strategies in the project) for both *traffic condition estimation* and *traffic management*. The first class of strategies use dynamic V2X communications to monitor traffic situations and detect anomalous cases in a more reactive, precise and efficient way. Examples of this class are "*Distributed traffic jam detection*" and "*Induction loop Replacement*". The first strategy is similar to what shown in Figure 1b).Vehicles exchange radio messages with each other and constantly run algorithms that, processing the information contained in the received messages, are able to fully autonomously detect traffic congestions without using any additional external information system (e.g. variable traffic signs). The information that are exchanged via radio concern individual properties of each vehicle: position, speed, heading

direction. Moreover, vehicles are supported by the knowledge of the road topology and their placement in it that they acquire through digital maps and GPS receivers. In the "*Induction loop Replacement*" strategy, fixed radio stations strategically located on the road network and called RSUs (Roadside Units) continuously receive radio messages from vehicles passing by. This permits to more dynamically monitor the traffic demand evolution and check the reliability of the data acquired by pre-existing inductive loops placed in the same points. The second class of strategies concerns *traffic management* completing the detection phase by traffic information dissemination or reaction policies. "*Event based traffic condition notification*", for example, concerns situations where vehicles are informed via radio transmissions about a given traffic event so that they can react in a proper way (e.g. avoiding a jam by taking alternative routes as explained for the situations of Figure 1). Also, in "*Emergency vehicle*", a situation is simulated where an emergency vehicle notifies its presence along its route by transmitting radio messages. Upon receiving these messages, RSUs placed at intersections trigger traffic lights so that priority for the emergency vehicle is given. In addition, all the vehicles receiving the radio warning stop at uncontrolled intersections, so that the emergency vehicle is able to "blindly" go through them. For a more detailed description of the strategies simulated in the project, please refer to [8].

iTETRIS strategies will be evaluated over four scenarios reproducing existing locations and traffic situations identified on the city of Bologna (Italy). The scenarios concern areas of different size and traffic capacity, ranging from urban streets, secondary roads up to suburban resolution. The traffic characteristics considered have been chosen due to their easy applicability to other European cities. For example, "*Pasubio/A. Costa*" is a scenario containing the city stadium, and thereby can be used to emulate traffic flows variations due to particular events at the stadium. The traffic management of such situations will be made by exploiting local alternative routes, which in turn may affect the traffic on adjacent parts of the road network. Another traffic scenario is the "*Orbital/highway*". Since orbital road and highway of Bologna run parallel to each other, vehicles driving on one of the two can be suggested to switch on the other one to avoid high traffic loads and so distribute the traffic flows in a better way. "*Open Market Fair/Irnerio*" and "*Ring way/Irnerio*" scenarios (see Figure 3) concern the ring way surrounding the city center, and a shortcut road connecting two points of the ring. These two scenarios are distinguished in terms of the anomalous traffic situations which are simulated. As shown in Figure 3, RSUs can be virtually deployed in strategic points of the road network, e.g. mounted on traffic lights. In this way, they are able to implement wireless communications with vehicles in order to perform the above mentioned cooperative traffic strategies, like dynamical adaptation of traffic light phases, detection of malfunctioning in loop detectors system, or induction loops' replacement by V2X systems. In addition, the scenario depicted in Figure 3, along with suitable RSU deployments can be used to simulate an even wider spectrum of strategies, e.g. to compute optimal routes to connect two points or to analyze car rerouting solutions based on traffic condition notifications or centralized traffic policies.
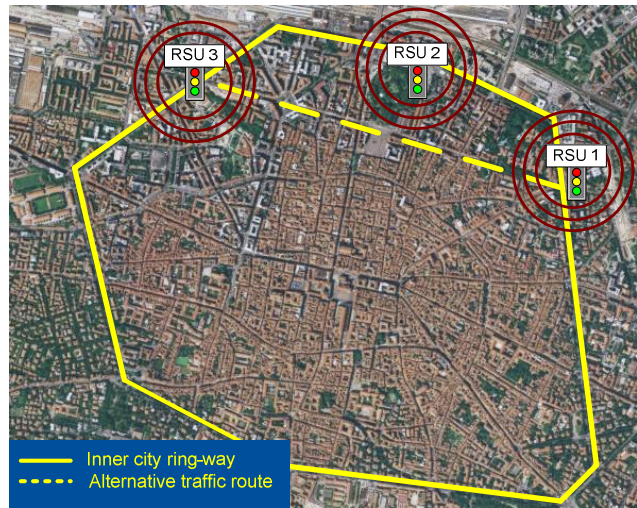

Figure 3: An example of the iTETRIS simulation scenarios over the city of Bologna

IV. CONCLUSIONS

This paper has presented the European iTETRIS initiative to build and test large scale simulations of cooperative ITS solutions for efficient road traffic management. Thanks to its extended vision in evaluating the effectiveness of such solutions, iTETRIS aims at being a valid supporting tool for City Authorities to realize whether cooperative systems can help in fulfilling the objectives dictated by specific urban traffic policies. As a simulation platform engineered for this purpose, iTETRIS can preliminarily verify the applicability of cooperative systems prior to "blindly" investing economical resources for their physical deployment.

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