ICT-MobileSummit 2009 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2009
ISBN: 978-1-905824-12-0

Poster Paper

iTETRIS: the Framework for Large-Scale Research on the Impact of Cooperative Wireless Vehicular Communications Systems in Traffic Efficiency

Javier GOZALVEZ[1], Siebe TURKSMA[2], Lin LAN[3], Oscar LAZARO[4], Fabio CARTOLANO[5], Eric ROBERT[6], Daniel KRAJZEWICZ[7], Ramon BAUZA[1], Fethi FILALI[8], Matthias RÖCKL[7], Jeremie LEGUAY[6], Carlo MICHELACCI[5], Jaap VREESWIJK[2], Julen MANEROS[9], Ainara GONZALEZ[4], Massimiliano LENARDI[3]

[1]University Miguel Hernández of Elche, Spain [2]Peek Traffic, Netherlands [3]Hitachi Europe, France [4]Innovalia Association, Spain [5]Municipality of Bologna, Italy [6]Thales Communications, France [7]DLR, Germany [8]Eurecom, France [9]CBT, Spain

Abstract: Cooperative vehicular ICT systems have been identified as an attractive technology to improve traffic management and safety, while providing Internet on the move. To achieve these objectives, cooperative vehicular communication systems allow the dynamic exchange of messages between vehicles, and between vehicles and infrastructure. To ensure the efficiency of cooperative vehicular ICT systems, it is crucial that the communication protocols are adequately designed and optimised, and that the applications using such communication capabilities are tested under realistic conditions. In this context, this paper presents the EU-funded iTETRIS platform that is being created to allow for a realistic and accurate evaluation of the design and impact of cooperative vehicular communication systems and traffic management policies under realistic large-scale scenarios.

Keywords: cooperative vehicular ICT, wireless communications, heterogeneous systems, simulation platform, traffic management.

1. Introduction

Mobility has had an increasing impact on worldwide economical and social development over the last decades, which is highlighted by the fact that up to 40% of World Bank loans have been used on transport projects [1]. However, current and expected future road traffic levels are increasing congestion levels, road fatalities and transportation pollution. In fact, it is currently estimated that there are still over 1.4 million accidents and 40.000 road fatalities on the 25 European Union roads every year, with a cost of around 200 billion €/year [2]. DG TREN (Directorate-General for Energy and Transport) has also estimated that the increase in the number of vehicles has contributed to 10 % of the network being affected daily by traffic jams [3], with congestions costs amounting 50 billion € per year. In terms of environmental pollution, the European Commission estimated that road transport consumed in 2002 approximately 26% of the total energy consumption in the EU, resulting in 835 million tonnes per year CO2 emissions (85% of the total transport emissions).

To address these problems, various ICT technologies have been proposed over the past years (e.g. Transit Signal Priority or Traffic Incident Detection). A further innovative technology to address the ambitious European goals to reduce road accidents, traffic congestions and transportation pollution is the development and future deployment of cooperative vehicular ICT systems. Through the use of wireless vehicular communications, cooperative systems will be able to assist the driver through the dynamic exchange of messages between vehicles (Vehicle-to-Vehicle -V2V- communications) and between vehicles and infrastructure (Vehicle-to-Infrastructure -V2I- communications). Such exchange of messages will allow detecting road dangerous situations and road traffic congestions. In addition, the use of V2X communications can be used to ubiquitously provide real-time traffic information and re-route vehicles through an optimal path, thereby reducing congestion levels and transportation environmental pollution. It is important to note that cooperative systems are part of the EC's Intelligent Car Initiative.

The European cooperative vehicular research activities started under the 6th EU Framework program, with projects like CVIS, Safespot or Coopers investigating the potential of V2V and V2I communications to address current and future mobility challenges. To validate and better estimate the impact of cooperative vehicular ICT technologies, several preparatory Field Operational Tests (FOTs) have been launched under the 7th Framework Programme. Although FOTs will provide a very valuable feedback on the impact and adoption of new in-car ICT technologies, their time-limited duration and the consideration of a maximum of 3000 equipped vehicles prevents to directly extract conclusions on the effect of cooperative vehicular communication systems in large-scale scenarios. Such estimate is needed to develop cooperative traffic management solutions given that the decisions adopted in a road traffic location can significantly impact road traffic conditions in adjacent roads. To overcome this limitation, and accurately evaluate the benefits of cooperative vehicular ICT technologies, the European FP7 iTETRIS (an Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions, http://ict-itetris.eu/) project aims to implement an open-source integrated wireless and traffic simulation platform that will allow testing and optimising V2V and V2I communications and cooperative traffic management strategies under large-scale scenarios. To this aim, iTETRIS addresses the following key aspects:

- Integrated standardised open-source traffic and wireless simulation platform. The project is working on the development of an open source platform that by integrating traffic and wireless emulation capabilities will allow accurately estimating the impact of cooperative communication technologies on traffic management.
- Large scale trials. To overcome the large-scale limitations of current cooperative communications and traffic management research activities, iTETRIS will model large-scale scenarios through the advanced traffic database and monitoring system available at the city of Bologna.
- V2V and V2I communications and networking protocols. The availability of a realistic, large-scale and integrated traffic and wireless simulation platform would allow testing and optimising novel, reliable and contextually dynamic V2V and V2I communications and networking protocols. These include geo-routing and data dissemination policies, as well as strategies on how to optimally integrate V2V and V2I communication capabilities.
- Advanced cooperative traffic management policies. The capacity to dynamically exchange information between vehicles and between vehicles and infrastructure will allow developing, testing and optimising novel cooperative traffic management policies designed to reduce traffic congestion and travel times by introducing dynamic traffic re-routing and improving traffic flows detection.

2. European ITS Communications Architecture

To ensure the alignment of the iTETRIS platform with the major international and research standardisation efforts in cooperative vehicular ICT systems, the platform is developed following the recently published baseline European ITS communications architecture [4]. This architecture, illustrated in Figure 1, has been developed by the European specific support action COMeSafety, as a joint effort with the projects COOPERS, CVIS and SAFESPOT, the Car2Car Communication Consortium, ETSI, IETF and ISO, and also with input from IEEE and SAE. The proposed architecture considers four different subsystems (vehicle, roadside, central and mobile) that can communicate over a wide range of wireless or wired communication media. It is important to note that this architecture has many similarities with the CALM architecture developed under the ISO TC 204 WG16. In particular, the new architecture maintains the CALM objective to allow for seamless communications over multiple communications technologies.

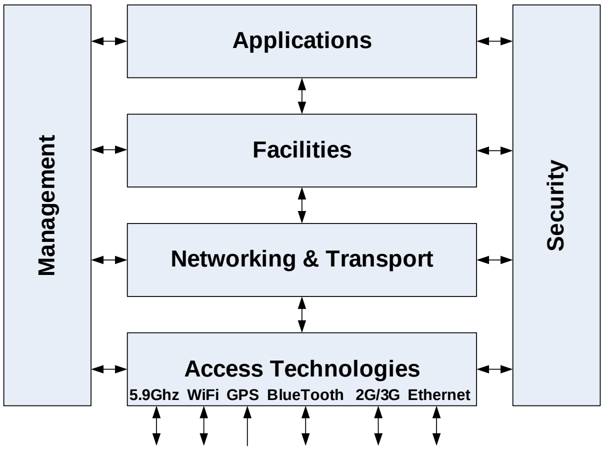

Figure 1. European ITS Communications Architecture.

<u>Access Technologies</u>

As illustrated in Figure 1, the European ITS Communications Architecture considers a variety of communication technologies that allow for short, medium and long distance communications, as well as infrastructure and ad-hoc communications. The architecture will then include algorithms that will select at each point in time the most appropriate communications technology; the development of such algorithms is part of iTETRIS objectives.

<u>Networking and Transport</u>

The European ITS Communications Architecture considers IPv6 for ITS networking and transport functionalities, with new additions from the IETF working groups NEMO and MONAMI. Given the geo-referenced nature of many traffic applications, a GeoRouting functional block is specifically being defined. An ITS Network functional block grouping many ITS functions, in particular those needed for the operation of the 5.9 GHz radio interface (e.g. management of broadcast and multicast transmissions, and development of efficient congestion control policies) is also being designed. In terms of transport protocols, the proposed architecture considers TCP/UDP and an ITS Transport block that is being defined to support the integrity of data transfers for fast moving cars. The architecture also considers the development of handover algorithms between various roadside stations, and more interestingly, vertical handovers between heterogeneous systems based on the application needs, system loads and coverage.

Facilities

The Facilities block handles application support, information support and session support functionalities. Application support refers to functionalities such as download and initialisation of new services, automatic discovery, and HMI capabilities. Information support handles data management, considering that data will be mostly geo-referenced and location specific. In addition, it is important to note that the utility of the data exchanged will be time-dependent, which requires the data to be validated so that users trust its content. Session supports handles the creation and maintenance of a link between nodes, with different implementations depending on the application and its time-critical nature.

Management

The management functionalities include: selecting the interface per application; monitoring and managing the communications interface selected; managing the security and privacy functions based on the current application and employed ICT technology; managing transmission permission and priorities; and managing the policy used to set and maintain all logical functionalities in a given node. It is important to note that the requirements, and consequently the management functionalities and operation, will vary depending on the application needs. This mainly concerns the management of traffic safety applications that generally require low latency and interference-free communications.

Security

The security functional block is aimed at preventing external attacks, ensuring that the information exchanged is correct and trustworthy, and guaranteeing the user's privacy. At this stage, iTETRIS will not implement the security management functionality, although collaboration with security cooperative vehicular ICT projects will be welcome.

Applications

The architecture currently addresses traffic safety and efficiency applications, and value-added services. Although iTETRIS is particularly focused on traffic efficiency applications, the platform can also be used for testing and optimising other applications. Traffic efficiency applications of interest include: Adaptive Electronic Traffic Signs, Route Guidance and Navigation, Traffic Flow Optimization, and Freight and Fleet Applications.

3. iTETRIS Simulation Platform

iTETRIS aims to cover an existing gap in the area of cooperative ICT-based traffic management R&D through the implementation of a large-scale integrated wireless and traffic simulation platform. In fact, iTETRIS aims to bridge the gap between the low-medium modelling accuracy and medium-large test-bed size characteristic of theoretical studies, and the high modelling accuracy low-medium test-bed size characteristic of FOTs. In this context, the iTETRIS platform is aimed at accurately evaluating the potential benefits of cooperative vehicular ICT systems to improve road traffic management under realistic conditions and large-scale scenarios, and provide indications on how the novel ICT cooperative systems should be configured and employed to maximise their potential. To achieve its objectives, iTETRIS is integrating (see Figure 2) two widely used open source platforms, SUMO (http://sumo.sourceforge.net/) and ns-3 (http://www.nsnam.org/). The software integration is being designed to reduce computational costs, and allow for scalable large-scale accurate simulations.

SUMO is an open-source microscopic platform developed by the German DLR laboratory that emulates traffic movement continuously in space and discretely in time. iTETRIS will further improve SUMO by incorporating aspects such as fuel consumption and pollution modelling. To realistically model large-scale traffic scenarios, iTETRIS partners are currently working at characterising and parametrising traffic flows in selected large-scale scenarios in Bologna so that they can be reproduced in SUMO.

iTETRIS decided to adopt the newly released communications ns-3 platform after analysing the modelling capabilities and future perspectives of the ns-3, ns-2 and OMNeT++ open-source wireless communications simulators. The analysis was conducted based on the current development status of the simulators (including the radio technologies and protocols available), their capabilities to perform large-scale simulations and whether the structure of the simulator allows multi-radio/technology nodes.

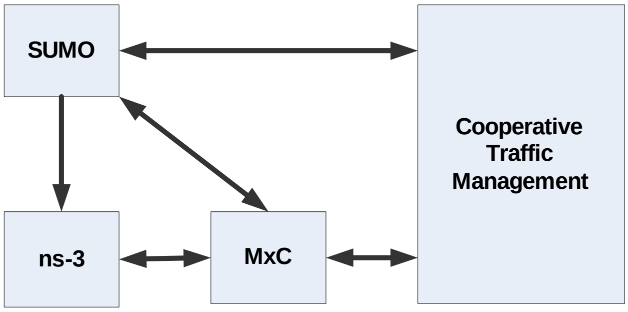

Figure 2. Integrated iTETRIS simulation platform.

In the iTETRIS platform, the cooperative traffic management centre will take decisions on how to route the traffic based on the current traffic conditions (obtained from SUMO), and will then inform vehicles using the message exchange communications (MxC) functional block; all vehicular communications will be emulated in ns3. V2X communications capabilities can also be exploited to improve road traffic estimates. Such estimates will be derived in the MxC based on the ns3 emulated vehicular communications. The estimate will then be passed to the cooperative traffic management centre that will apply the adequate traffic management policies.

3.1 iTETRIS Communication Technologies

iTETRIS is aimed at analysing the potential of V2V and V2I for road traffic management in a multi-technology communications scenario. In this context, the iTETRIS platform will implement the following four wireless communications technologies:

- European 5.9 GHz ITS. This technology is based on the IEEE 802.11p and IEEE1609 standards, and focuses on low delay V2V and V2I communications. The technology is particularly suitable for traffic safety applications, although it can also be used for traffic management. However, its CSMA operation requires the development of adequate congestion control and multi-channel management techniques. To date, 30MHz of spectrum (5875-5905 MHz) has been reserved at the European level for 5.9GHz ITS systems. It has been proposed to divide this spectrum into three 10MHz sub-channels, one being devoted to operate as a control channel, and the other two as service channels. The control channel will be the key channel over which vehicles and road side units will broadcast their presence and services. The first service channel will be the main service channel for safety and efficiency messages, while the second one will be used with low transmission power for very short range communications. To date, it has been proposed to automatically assign channels based on the application class and priority of a message. However, the multi-channel and multi-radio communications capabilities of the iTETRIS platform will allow testing more advance channel management strategies aimed at reducing channel congestion and efficiently distributing communications across the different channels and technologies.

- UMTS is a cellular system with moderate delay communications that can offer various transmission bitrates and QoS levels. One of the major advantages of UMTS for traffic management applications is that it currently benefits from a good coverage throughout Europe that will certainly improve over the years. On the other hand, the use of UMTS requires the cooperation with cellular operators, and it is yet to be studied the network load that V2I traffic management applications could create on UMTS networks.
- WiMAX is another infrastructure based wireless technology that can offer medium and long range communications with moderate delay. The technology has been developed to offer high data rate communications, with full support for mobility with the new mobile WiMAX standard. It is also important to note that the WiMAX standard allows the deployment under an unlicensed 5GHz band, thereby offering the possibility to traffic management agencies to deploy their own ‘cellular-type’ system along their road network.
- iTETRIS also includes broadcasting technologies, and in particular the DVB standard, to account for the efficient and simultaneous broadcast of traffic management messages to multiple vehicles over large areas.

3.2 ns3 Scalability

OMNeT++ is widely used by the wireless sensor networking community. Several studies have claimed OMNeT++’s higher scalability compared to ns-2, but they are generally based on different modelling accuracy and complexity levels. The differences generally affect the physical layer that significantly increases ns-2 and ns-3 computational cost. As shown in [5], increasing the OMNeT++ physical layer modelling complexity with a more detailed interference model, a more realistic environment and a nonlinear battery consumption model, considerably increases the computation time and required RAM memory. In fact, the full OMNeT++ model presented in [5] required higher execution times than 802.11 ns-3 simulations with similar conditions that have been conducted in iTETRIS to test the scalability of the three candidate open-source communication platforms.

iTETRIS opted for ns-3 over ns-2 due to: its more stable design for improved scalability (including parallelization capabilities) with a refined memory management; its modularity; the current 802.11 and WiMAX ns-3 modelling; the possibility to port ns-2 code to ns-3; and the core implementation of a node’s capability to support multiple radio interfaces and multiple channels. While multi-channel capacity will be crucial to investigate 5.9GHz ITS channelization policies, the multi-radio property will allow investigating strategies to integrate V2V and V2I communication capabilities and support vertical handovers among heterogeneous technologies.

To validate the selection of the ns-3 simulation platform, it is important to analyse its capabilities to simulate large-scale scenarios. At this stage, it is important to note that ns-2 had strong RAM memory problems for large-scale simulations modelling over 10000 wireless nodes (iTETRIS is considering scenarios with up to 20000 wireless vehicular nodes). In addition, while ns-2.29 was capable to simulate large-scale simulations, ns-2.33 was not able to handle simulations with over 8000 communicating nodes. To analyse the ns3 large-scale simulation capabilities, a simulation analysis considering 20000 vehicles communicating using the 802.11p 5.9GHz wireless ITS technology was conducted. Despite the fact that iTETRIS considers up to four radio access technologies, the simulation capabilities study only considered 802.11p since it is the technology requiring the higher computational cost given that all vehicles need to periodically broadcast Network Layer

(NL) beacons, or Cooperative Awareness Messages (CAM), with a 2Hz frequency in Europe and a 10Hz frequency in the US. The beacons contain information (e.g. node's ID, position and speed) needed to detect nearby vehicles, potential risks of collisions and traffic congestion conditions. Figure 3 shows the ns-3 default distribution execution time needed to emulate 40 seconds of road traffic conditions considering a 727 vehicles/km^2 vehicular density, a transmission range of 700meters and a 10Hz NL frequency ('Default' scenario). These parameters result in that there are around 1000 vehicles within the transmission range of each vehicle. Although this represents a very dense scenario, and therefore a worst case in terms of large-scale simulation computational cost, it is important iTETRIS considers congested environments. To understand the experienced high execution times, it is important to highlight ns-3's detailed PHY layer simulation modelling. To reduce the simulation time, modifications on ns-3 simplifying the interference management ('Mngt.' scenario) or the interference calculation ('Interf.' scenario) have been conducted, obtaining considerable simulation time reductions of up to nearly 30% (see Figure 3) without sacrificing the result's accuracy; in the worst case, a 1.8% difference in the number of packets correctly received was observed for the two modifications compared to the default ns-3 distribution.

The emulated environment represents a worst case scenario. As a result, it is interesting to check the simulation times that will be required using more realistic communication assumptions, i.e. different communication ranges and packet rates. First of all, it is important to note that 802.11p 5.9GHz systems will require advanced congestion control policies to avoid overloading their CSMA-based control channel. In this case, under congested road traffic conditions, it would be useful to reduce the communications range, resulting in fewer communicating neighbouring nodes and reduced channel congestion. A similar effect would be obtained by reducing the packet rate at which NL beacons are transmitted. Figure 3 also plots the execution times that will be obtained by reducing the communications range to 100m ('100m' scenario) and 2Hz NL beacon's packet rate ('NL-2Hz' scenario), highlighting the ns-3 simulation scalability potential as communication parameters are realistically defined.

Finally, simulation execution times always depend on the computing resource capabilities. The results in Figure 3 were obtained with a 1.6GHz Quad-Core Xeon HP Proliant server. Further reductions in execution times can be obtained with more powerful computational resources; increasing the server speed to 3GHz reduced execution times by over 21%. The obtained results show the ns-3 large-scale simulation capabilities, and the possibilities to further reduce its execution time by means of code optimisation, realistic emulation conditions, and adequate computation resources.

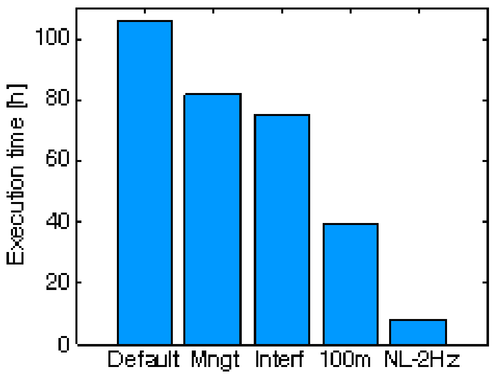

Figure 3. ns-3 large-scale execution times.

4. Cooperative Traffic Management Applications

The dynamic exchange of messages between vehicles, and between vehicles and infrastructure, will allow the deployment of new dynamic and intelligent traffic management applications aimed at reducing traffic congestions, travel times and transportation pollution. In addition, the introduction of ICT technologies into cars will transform them into active mobile probe sensors that can increase the accuracy of current solutions used to estimate the traffic conditions, for example inductive loops. In this context, iTETRIS is initially concentrating on the following cooperative traffic management applications:

- Traffic conditions estimation. The V2I communications capability could complement current traffic flow detection solutions by, for example, providing more accurate turning ratio information. This improved traffic estimation would allow increasing the capacity of intersections by better adjusting traffic light timings. In addition, the information received through cooperative vehicular communications could also help identifying malfunctioning loop detectors. Finally, the vehicles' capacity to dynamically communicate with each other and exchange position and movement information, could also provide the means to detect current traffic conditions without the need to further deploy any additional traffic detectors such as video cameras or inductive loops.
- Traffic re-routing and flow optimization. The use of cooperative V2X communications can also allow re-routing traffic based on current congestion levels. Providing alternative routes to drivers can be achieved through V2I communications or directly through geo-routing protocols using V2V communications in case no communications infrastructure is available. In addition, it is important to note that the use of V2I communications provides the capability to propose alternative routes to only a subset of vehicles, for example less pollutant vehicles, in comparison to Variable Message Sign (VMS) panels.

5. Case Study: City of Bologna

To develop and test the cooperative vehicular communications and traffic management applications, the Italian city of Bologna was selected as case study for iTETRIS given its medium-size, traffic problems, and strong support for the use of ICT technologies to improve traffic management. In this context, it is expected that cooperative vehicular ICT technologies could further improve the traffic conditions estimation, and allow a more dynamic traffic management resulting in reduced congestions and smoother traffic flows. To this aim, various traffic scenarios are being characterised and parameterised through the Bologna traffic database for their accurate reproduction in the iTETRIS platform. Such reproduction will allow testing and optimising the impact of cooperative vehicular communications on traffic management. To date, the selected traffic scenarios [6] include inner city big events (such as football matches), major inner city roads with important use of public transportation, inner city ring-way, and an orbital road interconnected and running besides a highway that allows traffic movement across the two road infrastructures.

As an example, Figure 4 shows the Bologna inner city ring-way, which draws a line between the Bologna-centre and the remaining urban city and represents the major road to cross the city given the Bologna city centre traffic restrictions. The figure shows a scenario in which there is a communication roadside unit (RSU) at every major intersection. The RSUs gathers traffic information provided by passing vehicles. Each RSU is capable to transmit/receive traffic information messages to/from vehicles and also forward the vehicle's information to the Cooperative Traffic Management Centre. Such information (for example, vehicle's speed, acceleration, heading and position) could be collected through any V2I communications technology considering their previously described characteristics. Through the RSU collected traffic information, the CTMC has a thorough and up-to-date knowledge of the current traffic conditions at different locations along the ring-way. Consequently, whenever the CTMC detects a road traffic congestion, for example in the area of RSU2, it may recommend vehicles approaching RSU1 to take alternative routes to RSU3 (dashed route in the figure) in order to decongest the inner ring-way. It is important to note that the V2I communication capabilities allow for the individualised traffic information transmission to vehicles compared to current Variable Message Sign solutions. Through this capability, only less pollutant vehicles (e.g. electric cars) could be allowed to cross the city centre to avoid the inner city ring-way congestion.

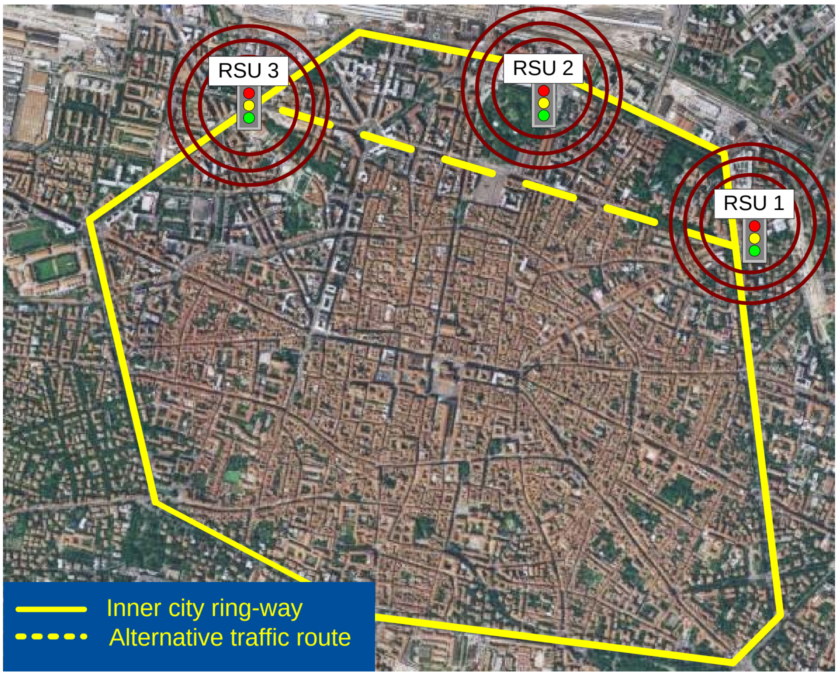

Figure 4. Bologna inner city ring-way.

6. Conclusions

This paper has introduced the FP7 iTETRIS project aimed at analysing the potential of cooperative vehicular technologies to improve road traffic management through V2V and V2I communications and cooperative traffic management policies. To this aim, iTETRIS is working on implementing an open-source integrated wireless and traffic simulation platform that will be able to emulate large-scale traffic scenarios using the city of Bologna as a case study.

This paper has presented the iTETRIS architecture, its wireless communications modelling capability, the simulation platforms selected, and examples of potential cooperative traffic management policies that can be applied in the city of Bologna. It is important to emphasize that iTETRIS will be able to simultaneously emulate various V2V and V2I communication technologies (WAVE, UMTS, WiMAX and DVB). As a result, it has been necessary to perform an in-depth study of the wireless simulation performance and scalability requirements to decide on the optimal iTETRIS wireless communications simulation platform. Once fully implemented, the iTETRIS platform will be used to investigate vehicular communication protocols, including geo-routing and data dissemination, in addition to studying optimal strategies to combine V2V and V2I communication capabilities.

Acknowledgment

This work has been partly funded by the European Commission through FP7 ICT Project iTETRIS: An Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions (No. FP7 224644). The authors wish to acknowledge the Commission for their support.

References

[1] Transport and the economy: full report (SACTRA), Department for Transport, UK Government.
[2] On the Intelligent Car Initiative: Raising Awareness of ICT for Smarter, Safer and Cleaner Vehicles, Brussels, 15.2.2006, COM(2006) 59 final.
[3] Energy and Transport. Report 2000-2004, Directorate-General for Energy and Transport, European Commission, 2004.
[4] European ITS Communication Architecture. v. 2.0, COMeSafety, October 2008.
[5] E. Egea-Lopez et al., Simulation scalability issues in wireless sensor networks, IEEE Communications Magazine, July 2006, pp. 64- 73.
[6] F. Cartolano, C. Michelacci, A. Pio Morra, D1.1 - Traffic management: scenarios, database and policies (draft), iTETRIS, December 2008.