iTETRIS - A Large Scale Integrated Simulation Platform for V2X Communications: Application to Real-Time Traffic Management

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***Abstract*— With the identification of cooperative vehicular communication as an encouraging solution to real time traffic management problems, there has been efforts in evaluating more efficient communication technologies and applications. Field operational tests (FOTs) exist and provide precise evaluation tools but they have limitations. It is impractical to imagine evaluation of large scale city like scenarios with thousands of vehicles by conducting FOTs. This converges to the need of large scale advanced simulation platforms. This paper in context of the ongoing EU project iTETRIS, addresses issues concerning realization of a large scale integrated traffic and communication simulation platform within realistic traffic scenarios with objectives of evaluating different management strategies. Further, the paper aims to demonstrate the design methodology of iTETRIS integrated vehicular traffic management simulation platform with regards to achieving its goals in terms of its scalability requirements and targeted capabilities.**

Keywords- Intelligent Transport Systems, Large Scale Integrated Simulation, Real-Time Traffic Management, V2X Cooperative Systems, Traffic Management Scenarios, networking simulation

I. INTRODUCTION

Information and Communication Technologies (ICT) cooperative systems for road traffic solutions are yet at their R&D and standardization stages. The current work needs then to be evolved to more technological advanced solutions adequately optimized considering system deployment requirements and end-user applications. Co-funded by the European Commission Information Society and Media among the 7th Framework initiatives, iTETRIS [1] (An Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions) targets to extend state of art in simulation of wireless vehicular cooperative systems for evaluation of road traffic management services and applications. There is no large-scale evidence yet, as to which extent wireless vehicular communications can help to alleviate traffic management problems. Providing a quantitative impact of V2X communication in ITS applications is then one of the main goals of the iTETRIS project. In particular, iTETRIS addresses four important and distinct challenges: (a) road traffic and wireless integrated open-source simulation platform, (b) large scale trials, (c) realistic Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication simulation and (d) dynamic, distributed and self-autonomous ITS applications based on cooperative systems. iTETRIS development and specification makes close reference to standardization progress, which is undertaken by ITS technical committee within ETSI (European Telecommunications Standards Institute) [2]. This ensures that the developed simulation platform is compliant with main standards.

The present paper will be organized as follows: Section II will provide iTETRIS targeted simulation scenarios and information on the selected simulation applications/strategies. The communication scenarios are derived and presented based on the analysis of application requirements. In Section III, iTETRIS overall architecture is presented, specific effort is put in the definition of the overall architecture in order to provide the extensibility of the platform and user needs, while ensuring the overall performance efficiency even in a large scale simulation scenario. Section IV will be dedicated to the detailed analysis of networking simulation, developed over network-simulator version 3 (ns-3) [3, 4]. This section will provide network architecture to be implemented by the iTETRIS project as well as preliminary implementation plan. Conclusions will be given in section V.

II. iTETRIS SCENARIOS AND STRATEGIES

Real-time exchange of information among vehicles (V2V Communications) and with road infrastructure (V2I Communications) has the potential to improve traffic management. Although cooperative vehicular systems have been identified as a potential solution to improve traffic management, routing and data distribution policies suited to the operational characteristics of such environment need to be designed and optimized. It is also of great importance to investigate the adequate combination of V2V and V2I

This paper also includes contributions from all the other iTETRIS Consortium Partners: Thales Communications S.A., France (Project Coordinator); CBT Comunicación & Multimedia, Spain; Comune di Bologna, Italy; German Aerospace Center (DLR), Germany; Innovalia Association, Spain; Peek Traffic B.V., The Netherlands. *Project duration* - 30 months, started on July, 2008.

technologies to ensure the continuous and cost-efficient operation of traffic management systems based on these wireless vehicular cooperative solutions. So far, the evaluation and optimization of these communication protocols have been performed though test beds and FOTs. Despite the potential of FOT to get first insights into the benefits and problems faced in the development of wireless vehicular cooperative systems, there is yet the need to evaluate them in the long term and at large scale. To this aim, iTETRIS is devoted to the development of an advanced tool, integrating traffic and wireless communication simulators.

A. iTETRIS Scenarios

Having as target the simulation platform of large scale ITS traffic efficiency applications using dynamic V2X communications, it is important to develop and test the platform using realistic traffic scenarios. iTETRIS takes the scenarios from the City of Bologna, Italy. In order to identify traffic scenarios of interest and significance to iTETRIS goals, various factors and parameters related to traffic activities are analyzed such as the road topology, traffic regulations, traffic flow, events and traffic measurement data. The following iTETRIS scenarios are selected:

SC1: Pasubio - Andrea Costa / City Stadium: For evaluating impact on mobility due to events at the city stadium.

SC2: Open Market Fair / Irnerio: The inner ring-way surrounding the city, congestions due to market fair.

SC3: Ring way / Irnerio: This scenario extends SC2 to include localized problems (lane closure etc.).

SC4: Highway / orbital: Provides option to switch between the highway and the parallel running orbital to resolve congestion on one of them.

B. iTETRIS Strategies and specifications

For a thorough and realistic evaluation of cooperative communication systems, a list of traffic strategies have been identified according to iTETRIS purposes for its future simulation sessions. In the context of the iTETRIS system, a “strategy” means the application of a traffic management method for improving the traffic situation within a certain scenario, iTETRIS strategies have been chosen to be sure of considering all the functionalities that a sustainable simulation platform must implement to be reusable. The achieved improvement that strategies bring is measured using well-defined metrics. Following strategies have been considered within iTETRIS,

For demonstrating Traffic Condition estimation:

S1: Traffic Jam detection (distributed): This strategy consists of detecting in real time traffic jam situations by V2V communications, without intervention of traffic operation center.

S2: Travel Time Estimation (centralized): This strategy tends to measure and estimate in real time travel times by vehicles sending their travel time date to center via communication infrastructure.

S10: Identification of malfunctioning Loop Detectors. Vehicles send periodically their position information to center, which may be used to compare with induction loop data in order to detect their possible malfunctioning.

S14: (De-Centralized) Floating Car Data (FCD): This strategy evaluates the impact of penetration rate to floating car data as well as applications making use of FCD.

For demonstrating Traffic Management:

S3: Bus Lane Management with road recommendation: Bus lanes are flexibly opened for normal vehicles in case of low traffic flow, detected by Cooperative V2I communications.

S4: Lane Closure Warning without road recommendation: communications infrastructure stations broadcasts lane closure information to oncoming vehicles.

S5: Request based Personalized Navigation: vehicles establish connection with central station which provides navigation service based on personalized needs.

S6: Regulatory and contextual speed limit information: road side stations providing regulatory speed limit and advice information to drivers.

S7: Emergency Vehicle: emergency vehicle in mission sends request to intersection to obtain green light and inform its presence to vehicles nearby.

S8: Event Based Traffic Condition Notification: traffic management provides real time anomalous traffic condition information to vehicles in the concerned area.

S9: Traffic Light Adaptation by Traffic Management Centre: Optimization of traffic light control management by adaptation of traffic light priorities for certain queues and to dissolve congestions at critical points more efficiently.

S11: Induction Loop Replacement: traffic condition detection based on information sent from vehicles.

S12: Postpone departure time for road network balancing: based on real time traffic condition, traffic service center sends recommendation to postpone departure time.

S13: (De)Centralized Route Recommendation based on Travel Time Estimation: Estimation process similar to S2, considering the possibility to access the travel time in a decentralized manner.

S15: Routing in Traffic Light controlled Network: vehicles sends its route information to center, which sends back best route information to driver in order to pass traffic light controlled network with fluency.

In the process of selection of strategies, iTETRIS goes further to define strategy description via help of a template. In order to assure that the set of strategies covers all V2X functionalities, references to communication and network parameters have also been included in the template. Further, for realization of these strategies in a simulation and with an implementation perspective, the template demands the component diagram / implementation blocks, sequence chart (indicating message exchanges during simulation) and requirements for the iTETRIS platform components.

III. iTETRIS Simulation Architecture

iTETRIS proposes a 3-Blocks simulation architecture with a real-time closed-loop coupling between the traffic simulator Simulation of Urban Mobility (SUMO) [5, 6] and the Network Simulator 3 (ns-3). The third and central block is the iTETRIS Control System (iCS) which apart from providing a coupling and controlling entity between SUMO and ns-3, provides a user interface to the iTETRIS platform for the application development. One of the main motivations for definition of this three block architecture is to facilitate the usability and extendibility of the platform for future development. The assigned developers and the targeted users of the platform for each block are illustrated by the Fig.1.

Particular attention is paid to standard compliance. ITS station reference architecture as under definition and progress within ETSI TC ITS [2] is studied and adapted to this three block architecture.

Architecture Principles – 3-Blocks architecture

In view of the magnitude of the large scale simulation which iTETRIS targets to achieve (~ 20,000 nodes over traffic duration of 1 hour in a scenario from the City of Bologna, Italy) and considering the close-to-real networking and communications conditions requirement, specific principles need to be defined to achieve an exhaustive and yet modular architecture.

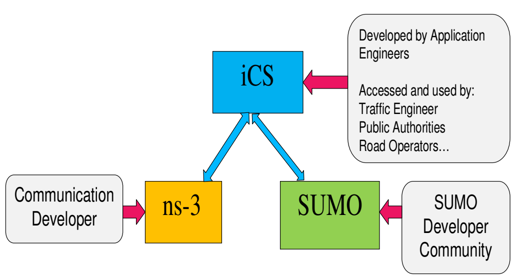

Fig 1.Targeted developers (ns-3, SUMO, Application Developers) / Users of the platform (traffic engineers, road authorities, general platform users)

Adhering to the defined objectives, iTETRIS architecture binds to the following principles:

1). User-friendly interface

As it can be observed in Fig. 1, iTETRIS distinguishes between 'targeted' user and developer categories. Each of the three iTETRIS blocks can be autonomously developed by using distinct programming languages, so that each developer doesn't need to be aware of other blocks' internal implementation, further, the applications can be created out of the platform and accessed without any specific development knowledge of the 'kernel' components.

2). Extensibility and maintenance

As iTETRIS proposes an open source platform, extensibility support is mandatory. This makes the simulator compliance to its goal to allow users to integrate and evaluate their novel protocols and algorithms based on their addressed strategies and mobility scenarios.

3). Optimization of computing resources

The 3-Blocks architecture design complements the efforts to reduce computational time and resources by intelligent placement of modules to reduce inter-block message exchanges. Other measures include usage of simple physical layer propagation models and features for topology or location specific activation / deactivation of communication algorithms. Given this consideration, facilities layer as defined within ETSI for cooperative systems is shared among iCS and ns-3 in order to reduce as much as possible messages exchange between these two blocks. It covers 5-7 OSI layers [7] and provides supporting functions to ITS application and to Transport & Networking layer. In principle, facilities used for application support and application information data base are put in iCS, while facilities supporting communications are implemented within ns-3. Based on these principles, the basic architecture of the integrated large scale simulation platform for iTETRIS can be understood as shown in Fig. 2.

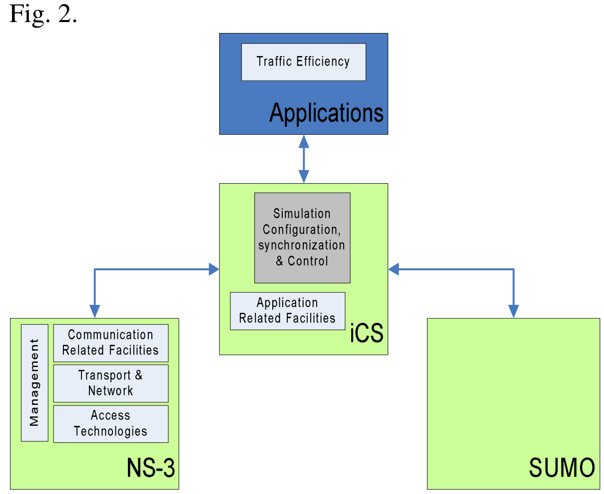

Fig 2. iTETRIS 3-Blocks Architecture

Message Interactions

The functioning of the architecture shown in Fig. 2 can be explained by describing the message interactions. To understand the message interactions between the blocks in Fig. 2, iTETRIS Strategy S2 “Travel Time Estimation (Centralized)” can be used. According to this strategy, communication infrastructure units (CIU) based on an iTETRIS suitable radio access technology ask vehicle to collect travel time along their routes. In order to accomplish this, broadcast messages are used. Vehicles receiving a second broadcast request message return the calculated travel time to the requesting CIU. The 'actors' involved would be the ITS Vehicle Station, a suitable CIU and the ITS Service centre, that decides the road segments of interest over which travel times should be calculated, and collects results to generate average values.

A clear perception of the real world operation can be attained by flowcharts. The flowchart demonstrates the events occurring in an equipped vehicle, when it enters the target area covered by the CIU requesting travel time computation. Primarily the strategy application logic is fed to the iCS 'User Interface'. The application logic configures the application definitions for the On Board Unit (OBU), Road Side Unit (RSU) (if used among the CIUs available) and the Traffic Service Centre.

After the initial set-up the coupled simulator implements the strategy. In a general way, SUMO is passing continuously vehicle positions and speed information to iCS, which further forward to ns-3 for geonetworking usage. iCS also need the mobility data for traffic efficiency evaluation usage. Secondly, iCS shall also send control commands and strategy information to ns-3 in order to initiate radio packet transmissions simulation. On the other hand, ns-3 needs to notify reception of radio packets/messages to iCS, which receives consequent decisions from the application. Finally, based on the decision made by application, iCS may need to send commands to SUMO in order to modify vehicle mobility e.g. vehicle passing route, vehicle maximum speed etc. As example, the subsequent message interactions of travel time estimation strategy can be represented by the sequence chart shown in Fig. 3.

A. *Analysis of Network and Wireless Simulation Platform: Choice of ns-3 for iTETRIS*

In view of the magnitude of the simulation which iTETRIS targets to achieve (~ 20,000 nodes analyzed over more than 1 hour real-time) and considering the close-to-real networking and communications conditions requirement, the choice of the network simulator has a significant influence on the execution time of the simulation runs.

For selecting the suitable network simulator, a comparative study was done on three widespread network simulators: ns-3, ns-2 [8] and OMNeT++ [9] because they suit the basic parameters required for the development of the iTETRIS project. The three network simulators were analyzed and compared with regard to several critical aspects.

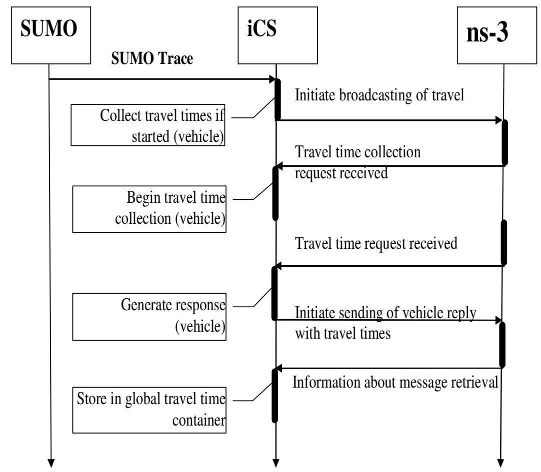

Fig. 3: Sequence Chart demonstrating message interaction for travel time estimation using iTETRIS architecture.

First of all, an important issue analyzed is which communication modules are available for each simulator, since this could be a decisive factor considering the heterogeneous nature of the iTETRIS platform. The future simulation platform should support several radio access technologies such as 802.11p, UMTS, WiMAX, and DVB. Consequently, multiple interfaces/multiple channels features have to be integrated in iTETRIS. Furthermore, this study paid special attention to the scalability capabilities of each simulator, given the large-scale simulation requirements of the iTETRIS platform. The analysis includes simulation tests and the study of the parallelization capabilities of the simulators. After a detailed analysis and preliminary tests, ns-3 was selected as the wireless simulation platform since it offers interesting features and capabilities which cover the main iTETRIS large scale simulation requirements. These capabilities include:

- ns-3 capability of large-scale simulation;
- ns-3 support for multi-Radio access interface and multi access technologies
- ns-3 support for better modularity and extensibility of source codes
- ns-3 support for parallel and distributed simulation.
- ns-3 better development support by project community compared to its predecessor, ns-2.

B. *Optimization of the simulation platform: Adaptation of Cooperative Awareness Message (CAM) for iTETRIS.*

Cooperative Awareness Message (CAM) [6, 10] is one of the basic features and functionalities of V2X cooperative systems. It announces the presence, position, speed and provides basic attributes of an ITS station to other ITS stations nearby, besides, it is employed to advertise the available services that an ITS station offers. CAMs are generated and broadcasted periodically. Broadcasting of CAMs is required as a basic function of ITS vehicles and road side stations mainly for safety applications such as collision avoidance. However, position, speed and other basic information included within CAM can be used by traffic efficiency applications. Broadcasting frequency of CAM ranges between 0.5Hz to 10Hz, depending on the requirement of application that make use of CAM information.

CAM being a heart beating message, plays an important role both for application and networking purpose. Due to the huge number of nodes in the large-scale simulations done in iTETRIS and its relatively high broadcasting rate, it is extremely important to reduce unnecessary computational load generated by this process. iTETRIS proposes mechanisms to simplify the implementation of CAM dissemination. With regard to the application requirements and simulated scenarios, two methods are proposed:

a) Grid based dissemination

The simulation scenario is divided into grids. The heart beating optimization specifies a different CAM dissemination rate for each grid. This way, the transmission rate could be higher in those grids identified as more relevant for the strategies under analysis and deactivated for the less interesting grids, thus reducing computational load and increasing efficiency.

b) Topology based dissemination

Topology based dissemination will be applicable in cases where the application demands for a particular CAM rate and/or for a specific section of the road topology. For example, this method may activate the CAM transmission of only those vehicles driving over certain road segments of interest, e.g. locations where traffic congestions usually occur.

IV. NETWORKING SIMULATION IMPLEMENTATION

A. *ns-3 architecture*

iTETRIS would implement the N&T (Network and Transport), part of Facilities (Communication Related) and Physical/MAC layer blocks in ns-3. General ns-3 implementation architecture is illustrated within Fig. 4. This architecture includes the following main components:

(i) C2C (Car 2 Car) Stack – The C2C Stack implementation is one of its kind for a simulation, the C2C non-IP Geo-Networking stack would be responsible for implementing a C2C specific transport layer, Network Layer containing C2C specific addressing, Geo-based routing protocols (Geo-anycast, Geo-broadcast, Geo-multicast and Topology based broadcast) and basic C2C functionalities like Beaconing, Location services etc. In iTETRIS, the network layer beaconing is implemented as a permanent process, which will be running in background. The ns-3 module in iTETRIS requires geonetworking position information to do dissemination. This position information is given by SUMO.

The C2C stack will also contain assisting functionalities like 'Store and Forward' which is needed to sustain communication in sparse network or at early system deployment phase. In such cases, with the use of the 'store and forward' functionality, the node becomes capable to 'store' the messages and 'forward' it once a suitable forwarder is within the range.

(ii) IP Stack – Parallel to the C2C network stack, there will be the existing IP stack in ns-3 (currently IPv4 available).

(iii) Facilities: The iTETRIS implementation in ns-3 will also be having C2C communication related Facilities layer blocks. These facilities will be responsible for components like message management, addressing mode support etc.

(iv) Vertical management layer implementation is mainly concentrated on the functionalities that select the communication stack and access technologies for message transmissions. Due to the complexity and project duration time, another vertical cross layer Security layer is not considered and implemented during the project phase.

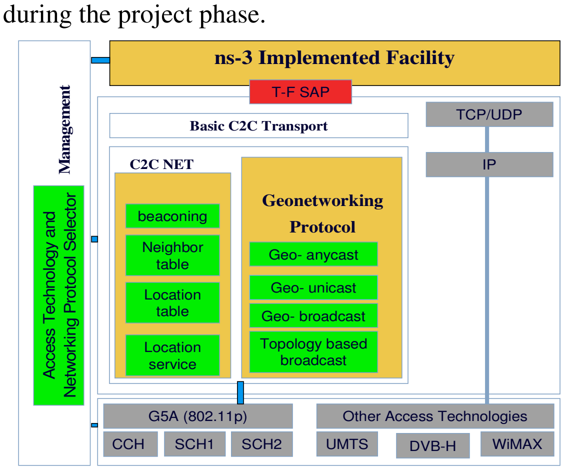

Fig. 4: iTETRIS C2C stack structure in ns-3

The iTETRIS simulation architecture as in Fig. 4 is in compliance to the ETSI standard, even though it is to some extent simplified, as iTETRIS will have two stacks and won't be having the third stack i.e. 'IP over C2C Net'. Such simplification is explained by having focus to provide a modular platform with a structural compliance to ETSI architecture. Other ongoing EU projects such as GeoNet [11], PRE-DRIVE C2X [12] are providing detailed technical specifications that are complementary to iTETRIS project and therefore are taken as inputs. To support the C2C stack structure (Fig. 4), iTETRIS proposes the message frame format as shown in Fig. 5.

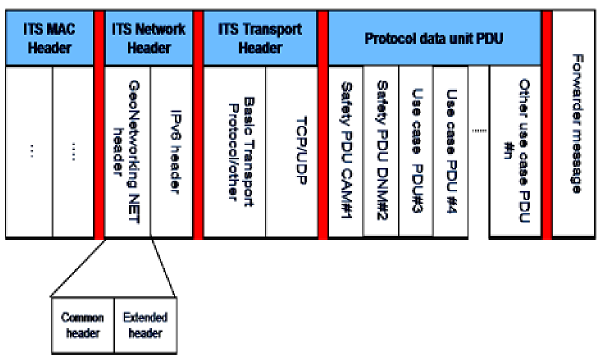

Fig. 5: Message Frame Format for iTETRIS

B. *Implementation*

A node in ns-3 implements a communicating station (mobile or fixed) and consists of a set of network interfaces ('NetDevices'), network and routing protocol stacks, and different applications

For development of C2C Geo-Networking stack in ns-3, the node structure is analyzed. An overview of attachment of ns-3 architecture can be observed in Fig. 6. This architecture is still under study and specification phase, it will be deepened and enriched in the future.

As depicted in Fig. 6, any communication stack needs to be attached on similar guidelines. The novelty here would be to include a C2C stack implementation in parallel to the current IPv4 (and IPv6 in future versions of ns-3) stack implementation in ns-3. Depending on the strategy requirement, the appropriate stack will attach itself to the node.

Apart from the C2C structure in ns-3, iTETRIS would require implementation of a C2C specific addressing scheme, headers/packets structure and modification of the tracing mechanisms.

V. Conclusion

In context of iTETRIS, the paper highlights the constraints and issues associated with large-scale cooperative systems simulations. It also presents a strategy description template which includes exhaustive information required for achieving a simulation with such capabilities and magnitude. The detailed comparative study between existing network simulators allows selecting the most suitable one for the iTETRIS platform. Further, the paper also presents a holistic

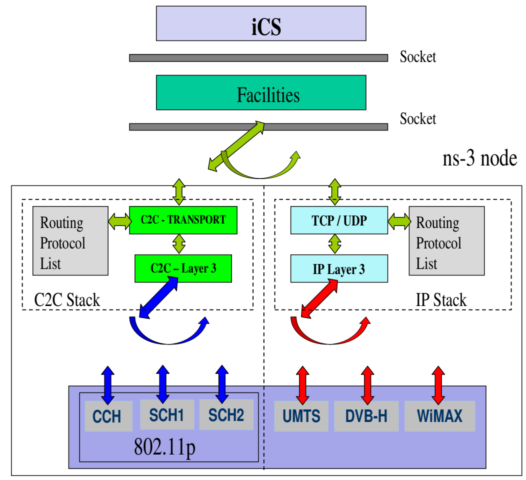

Fig. 6: C2C stack implementation in ns-3: conceptual overview

view of the architecture and an overview of the realization methodology in ns-3.

The expected benefits from iTETRIS include better optimization of communication protocol design, which will improve the QoS levels provided by cooperative systems. iTETRIS could become the *de-facto* platform for protocol evaluation at C2C-CC [10] and ETSI levels, which are targeting standardization of the interoperable V2V/V2I technologies.

iTETRIS project has entered the phase of specification definition and implementation, more detailed and specific progress information will be provided in future papers and publications.

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