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Test Environment Design for Wireless Vehicle Communications

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***Abstract*— The integration of new wireless technologies with vehicle computing systems has opened the doors for new fields of applications such as intelligent transportation systems. Vehicular *ad hoc* networks emerge as the technical basis in solutions aiming to improve road safety and efficiency as well as driving comfort. This paper discusses different factors that influence the performance of wireless vehicle communication systems and proposes a general design for the construction of a test environment for these systems. A comprehensive list of different parameters that affect the system performance is compiled. Next, these parameters are analyzed and quantified to serve as guidelines when establishing and designing components of a suitable test environment. This test environment should provide a platform that enables researchers and engineers to identify possible bottlenecks in the network functionality as well as allowing test, assessment and verification of as many of the relevant parameters involved in the *ad hoc* communication as possible.**

***Index Terms*— vehicular *ad hoc* network, test environment, test-bed, simulator, wireless communication.**

I. Introduction

The sectors of vehicular and communication technologies have matured and several research initiatives, e.g., [1]–[3] have been focused on overcoming dangerous roadway situations by taking advantage of new technologies, equipment and infrastructure. The aim is to achieve reliable and cooperating intelligent systems capable of contributing to safer, more efficient roads by e.g. delivering warnings and roadway information on time and thus increasing passenger safety. When vehicles are on the road, the major technical challenge is the timely transfer of data. The high mobility conditions that vehicles are subject to, limit the ability to establish a centralized, low delay network along the road. Various cell-phone operators already provide a centralized, global network. However, such systems suffer from fairly long delays, which qualify them for satisfying some, but not all the needs of safety-related applications [4]. For this reason, the creation of *ad hoc* networks capable of organizing themselves to extend the horizon of the drivers is tractable, since this enables low delay communications even in places without infrastructure.

Vehicle *ad hoc* networks (VANETs) represent the basis of the new generation of *intelligent* transportation systems. They provide vehicles with the possibility to exchange information with each other and with roadside infrastructure to perceive traffic and road conditions in their environment. The development of VANETs involves problems with characteristics that are dramatically different from those of generic *ad hoc* networks. The lack of a master node or a centralized entity to manage the network together with the high mobility of the nodes are generally the main problems in the design and assessment of such networks. VANETs are characterized by rapid topology changes, small effective network diameter and unfavorable channel characteristics [5], [6]. While several aspects related to vehicle communication have been investigated by researchers, many problems still remain. For example, most existing test platforms, e.g., [7]–[9] developed to evaluate the performance of such systems address only a subset of the challenges involved in wireless vehicle communications. Their main focus is on modeling and simulating some specific elements involved in inter-vehicle communication (IVC) such as medium access, vehicle mobility patterns, traffic load or routing. However, the outlined challenges for VANETs raise the demand for a more comprehensive testing environment where several and preferably all elements involved in IVC can be evaluated jointly. Such a test platform will support engineers in their work and will bring valuable inputs to researchers involved in the development process. This paper proposes a design of a test environment for VANETs based on an investigation of the underlying parameters that affect the performance. The following approach was adopted:

- Since so many interrelated factors and parameters affect the performance of a VANET system, we believe that it is essential to be thoroughly familiar with the properties that characterize wireless vehicle communications. Thus, the first step is to analyze VANETs and qualify relevant parameters affecting their performance.
- The second step is to determine the requirements of a test environment intended for evaluation of VANET performance. The platform should allow testing, evaluation and verification of as many parameters as possible of those identified in the first step.
- Finally, based on these requirements, a general architectural proposal for a comprehensive test environment can be given.

The remainder of this paper is structured as follows. Section II contains an approach on how to quantify a VANET environment by identifying a number of parameters affecting its performance. The results of this section serve as basic

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guidelines for further investigations regarding the construction of an appropriate test environment for VANETs, as described in Section III. Finally, our conclusions are outlined in Section IV.

II. Qualified Parameters for VANETs

Much effort and research in the literature is spent on the factors that influence the performance of wireless vehicle communication systems. The discussion boards how such parameters affect the construction and development of a general architecture for VANETs. In [10], the dissemination of safety-related information in a VANET is studied. Assuming a layered protocol design, it is argued where and how functions related to data dissemination and transport could be implemented. In [11] the decomposition of the VANET functionality into a combination of the typical OSI layered approach and an architecture tailored to the specific needs of VANETs is discussed. The result is a cross-layered architecture in which dependencies among parameters can be observed. Also in [12] a cross-layered architectural design is used, this time in safety/comfort-related applications, and the involved networking challenges are discussed. The results outline the main challenges for VANETs to be medium access control (MAC) and routing protocol related issues. The challenges in *ad hoc* networks obtained from the construction of a test-bed are described in [13]. Here a set of scenarios are used to characterize an *ad hoc* network environment. Issues such as wireless technologies, routing protocols, security and signal propagation constraints are addressed.

Our approach is to describe a collection of parameters, where each parameter represents or affects an integral part of the vehicle network characteristics. Examples of parameters are the type of routing protocol used, the adopted addressing mode (e.g., geocasting, broadcasting), the system latency or the transmission error rate. Our selection of parameters was driven by the characterizing features of VANETs on the one hand and the desired applications on the other hand, much the same way as the selection done in, e.g., [14]. However, in order to provide a more comprehensive view than the discussion provided in [14], we categorized the parameters according to different perspectives. Three distinct perspectives are outlined: "Evaluation perspective", "OSI layer perspective" and "Dependency perspective". The entire collection of parameters tries to provide an as complete as possible view of the field of VANETs with its unique conditions and requirements as well as outline the key characteristics for applications in this area [15].

A. Evaluation Perspective

For the first perspective we considered the nature of the parameter, i.e., we determine whether a parameter can be evaluated or tested. An "evaluated" parameter is a quantitative metric that can be described mathematically and has a certain unit assigned to it. Evaluated parameters are obtained either by means of measurement or by calculation using one or more other parameters. Transmission error rate is an example of a parameter that can be evaluated. "Tested" refers to configuration parameters, that can neither be measured nor calculated, but affect the characteristics of VANETs. This category comprises parameters such as the wireless technology used, the type of vehicle traffic pattern and also routing protocols. "Tested" parameters can be understood as degrees of freedom in the configuration for VANETs and also as the specific test setting for a desired application. Parameters in the "Evaluated" category can be seen as performance measurements of a given VANET composition. Table I shows the "Evaluation perspective" of the conceived parameters.

TABLE I

Metric: Evaluation Perspective

Evaluated	Tested
Geographic location	VANET applications
Velocity	Type of message spreading area
Acceleration	Location based services
Connection setup time	Message prioritization
Connection handover	Min throughput of application
Connection reliability	Max latency of application
Interference	Vehicle traffic density
Signal propagation	Data traffic pattern
Power consumption	Scalability
Transmission error rate	Addressing
Network connectivity	Wireless technology
Message spreading time	Network heterogeneity
Latency	Routing protocols
Jitter	Modulation scheme
Transmission rate	Message corruption/intrusion
Data traffic costs	

Note that the parameters Carrier frequency, MAC method and Network topology (peer-to-peer or centralized) are not listed. This is due to the fact that we assume that once the Wireless technology is chosen, these three parameters are also selected implicitly. The Modulation scheme, on the other hand, can often be changed within each wireless technology and thus it is listed as a separate parameter.

It can be seen that the number of parameters is fairly evenly distributed over the two categories. This implies that a suitable test environment should include features such that both evaluation and testing is possible. A VANET underlies a variety of configurations given by parameters listed under the category "Tested". For evaluation purposes, it should be possible to test different compositions of these parameters. Thus, it should be feasible to simulate, e.g., the efficiency of a routing protocol under varying types of message spreading areas, or to simulate the scalability for different wireless technologies, etc.

B. OSI Layer Perspective

Even though [11], [12] promote a full cross-layer model for VANET architecture design in order to optimize the overall network performance, we believe important insights can be gained by relating each parameter to its original layer. Consequently, in our second perspective the parameters are classified according to their layer of affiliation in the OSI model. In addition to the seven layers in the model, we also introduce an artificial layer for parameters which obviously

TABLE II

METRIC: OSI LAYER PERSPECTIVE

OSI Layer	Parameters
Layer 0	Velocity, Acceleration, Geographic location, Power Consumption, Message prioritization
Layer 1	Signal propagation, Interference, Transmission error rate, Modulation scheme
Layer 2	Transmission rate, Wireless technology
Layer 3	Connection setup time, Latency, Jitter, Connection handover, Connection reliability, Routing protocols, Message spreading time, Network connectivity, Data traffic costs, Network heterogeneity, Addressing
Layer 7	Data traffic pattern, Scalability, Max latency of appl, Vehicle traffic density, Message corruption/intrusion, Location based services, Type of message spreading area, VANET applications, Min throughput of appl,

could not be assigned to any specific layer, such as e.g., acceleration. This artificial layer was named layer 0. Table II lists the OSI layers with their respective parameters.

The table reveals that the parameters are distributed among the artificial layer 0 and layers 1, 2, 3 and 7. The layers 4, 5 and 6 are missing in our listing. The absence of these layers can be explained by the fact that VANETs are application specific networks that typically differ from other types of networks in that the applications are much more homogeneous. Further, there is a need for simplified, slimmed protocol suites to reduce latency for delay sensitive VANET applications.

Some parameters in the list could be mentioned in several layers simultaneously. Wireless technology is an example here. The specifications of a wireless technology standard commonly addresses not only layer 1 properties, but also properties from layer 2 and in some cases the whole protocol stack. However, the majority of wireless communications standards being considered for use in VANETs include Layer 1 and 2 and thus we assigned the parameter only to Layer 2 in order to keep a clear overview. Another example here is the message prioritization parameter which could be considered in all layers that contain methods for prioritizing the data. To follow the rule not to assign a parameter to more than one layer to keep a clear overview, the parameter is listed under the artificial layer 0. The same is true for power consumption since this depends on the transmitted energy, the routing protocol as well as the data aggregation and procession in the application layer.

The distinction of parameters among the OSI layers provides a dedicated view over the layered responsibilities in VANET development and permits to observe the complexity of the test environment design aiming to include all the elements that comprise the system. The parameters being distributed over so many different layers in the OSI model further suggests that VANET research is not only a question of improving existing technologies in a certain domain, but also requires new ways of how networking is conceptualized in general.

C. Dependency Perspective

In this perspective, we establish direct dependencies among the parameters. A direct dependency between two parameters exists if a parameter is directly influenced by another parameter. The parameters are represented as nodes and an arrow pointing from node A to node B means that the parameter A directly influences parameter B. Fig. 1 illustrates an example of such a relation whereas Fig. 2 depicts the dependencies found among the VANET parameters. Referring to the "Evaluation perspective", the parameters are represented as grey and white nodes respectively. Grey nodes indicate parameters that can be "Evaluated" and white nodes parameters that should be "Tested". We included this metric in Fig. 2 in order to observe possible relations among parameters of the different categories.

Further, we tried not to draw arrows between parameters that do not belong to the same or adjacent layers. Instead connections and dependencies are made through parameters in intermediate layers. This is done both to keep the figure as clear as possible and to illustrate the chain of dependencies among VANET parameters. An exception here is the layer 0 parameters Power consumption and Message prioritization since we believe these parameters affect more than one layer.

Several observations can be made from the assessment of this perspective. First, there are five nodes showing the most relations to other nodes: VANET applications, Network connectivity, Message spreading time, Routing protocol and Wireless technology. The high number of relations indicates that these parameters hold valuable information about the performance of a VANET. Note that these five parameters pertain to layers 2, 3 and 7 in the OSI layer perspective and belongs to different categories in the Evaluation perspective. The "tested" parameters: Wireless Technology, Routing protocols and VANET applications are outlined as the three most influencing factors in a VANET since they affect the highest number of other parameters and thus have the highest number of outbound arrows. The boxes VANET applications, Message spreading time and Network Connectivity show the highest number of inbound arrows, indicating that these parameters are affected the most by other parameters. Another interesting observation is that the parameters Message spreading time and Network connectivity are influenced both by "Evaluated" and "Tested" parameters and represent the main link between these groups by connecting the more part of the parameters from the two categories.

III. TEST ENVIRONMENT

In the previous section we compiled a list of parameters that quantify the performance of a VANET. The next step is to use the insights gained from this process to develop a

Fig. 1. The wireless technology used influences latency

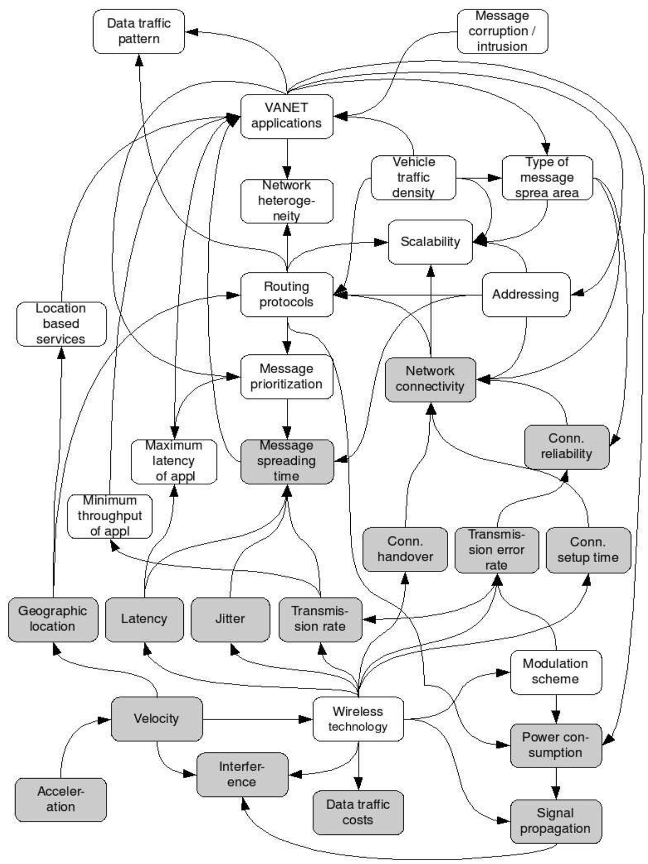

Fig. 2. Metric: Dependency perspective

suitable test environment that can test or evaluate as many of the identified parameters as possible. We have concluded that important parameters span several layers and that some can be measured whereas others have to be tested. Given the complexity, the amount of required resources, and other practical limitations, not all tests can be conducted using real-world experiments, and thus simulations will also be needed. However, computer simulations should not be the only tool. Simulations require assumptions to be made that may or may not affect the final performance evaluation. The assessment of real vehicular scenarios is important to the deployment and the standardization of the systems, technologies and protocols in vehicles and roadside infrastructure.

A. *Test Environment Architecture*

Based on the above reasoning, we propose an architecture design for a test environment for a VANET (TEV) consisting of three main components. The first component is a dedicated hardware platform, referred to as the test-bed, which is deployed inside the vehicles. This on-board test-bed sets up connections with other test-bed equipped vehicles and is thus the central component for parameters that can be evaluated. It enables observing the VANET behavior from an individual vehicle viewpoint. The second component is made up of simulated vehicles. The idea behind using simulated vehicles is to enable large scale and low cost VANET tests with

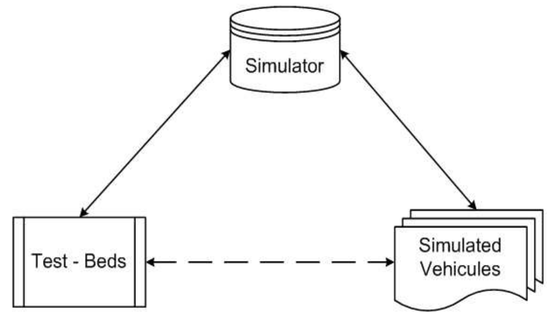

Fig. 3. TEV architecture

a high number of participating vehicles. Simulated vehicles comprise a mathematical model describing the characteristics of a vehicle in a specific network environment. Data, collected from the test-beds can further be used to model the simulated vehicles. The third component is referred to as the simulator, gathering data from all the deployed test-beds as well as the simulated vehicles. The simulator constructs a complete overview of the VANET and is used as a tool for network performance analysis and parameter assessment. It enables observing the overall behavior of vehicular networks and allows identification of potential bottlenecks in the system. An overview of the components of the TEV architecture is shown in Fig. 3. The dotted line between the test-bed and the simulated vehicles outlines a potential communication channel between real and simulated vehicles. It should be noted that the simulator does not distinguish between test-beds and simulated vehicles but abstracts the processing of received data to a common level. Using this approach, three advantages in the VANET performance evaluation are envisioned:

- The TEV allows evaluation as well as testing of different parameters that affect both each other and the overall performance of a VANET. This enables the assessment of technologies in many diverse areas such as wireless technologies, antennas, GPS receivers, etc. The test environment is open for extensions to increase modularity.
- The test-beds provide a possibility to obtain better and more accurate simulation results by means of the deployment of a small fleet of real-world vehicles on a road. This fleet is allowed to influence the simulated vehicles as well as the overall simulator.
- Since the parameters span several OSI layers, some need to be simulated whereas others can be evaluated or tested using real-world vehicles on a road. The simulator enables evaluation of complex parameters such as Scalability through the use of data from 'virtual' vehicles as well as real-world test-beds.

Similar architectural designs of VANET test environments have been used in [7], [16], although these papers lack a motivation for choosing this particular construction.

B. *Use Cases*

The use cases for this test environment are numerous. The first task could be to assess measured data from the test-beds in an attempt to reveal shortcomings in communication quality and outline particular improvements which could be made to existing communications standards. The standards IEEE 802.11p [17] and mobile WiMAX [18] represent wireless technologies that promise to extend existing protocol implementations to suit the requirements of wireless vehicle communications. However, as has been outlined in several related papers, the entire set of communication requirements for the diverse range of VANET applications can maybe solely be met by using a heterogeneous composition of wireless carries. The CALM [19] specification seems to be a promising approach in this context. In the choice of wireless technology, TEV and the Dependency perspective provide valuable input regarding which factors affect as well as which factors are affected by the performance of the wireless technology in question. For a first evaluation of applicable wireless technologies ordinary notebooks could be used as test-beds.

Various *ad hoc* routing protocols have been proposed recently, where location-based [20] (e.g., DSR, AODV and MPR) and position-based [21] (e.g., DREAM, GPSR and ALARM) routing protocols emerge as two main classes of protocols used within this field. However, research regarding sophisticated routing protocols for VANETs is far from finished. In this case the TEV and the Dependency perspective also provide valuable input.

As a further step, actual applications can be investigated and tested according to their feasibility for VANETs. This experience could serve as the basis for a set of application profiles, classifying applications according to similar requirements. To continue this work, limits for parameter values in order to satisfy certain quality constraints required by the application profiles can further be established.

More precise results can also be achieved with specialized test-bed components, as proposed in [15], leveraging the communication aspects in VANETs. The data assessment by the TEV could be further enhanced by a database, hosting detailed requirements for specific VANET applications. In continuing research on VANETs, such a database could be the basis for quality of service (QoS) implementations within this field.

IV. Conclusions

In this paper, an architectural design for the development of a test environment in the field of wireless vehicle communications is presented. While investigating existing simulation platforms for VANETs, a new design approach was adopted especially intended for meeting the diverse requirements of this field. We quantified the communication environment of VANETs by means of specific parameters, each affecting and influencing the performance of a VANET. In order to support the identification of contiguity among the parameters, three different perspectives were outlined: the evaluation perspective, the OSI layer perspective and the dependency perspective. Based on this, an architecture that enables evaluation both by means of measuring and testing, that considers parameters from all relevant OSI layers and interdependencies among parameters was suggested.

The developed concept should be beneficial for both researchers and engineers in the study of aspects related to *ad hoc* networking in general and wireless vehicle communications in particular.

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