Smart Vehicles for Smarter Cities: Context-Aware V2X to Improve QoI

Amirton B. Chagas
Centro de Informática – Universidade Federal de Pernambuco (UFPE)
Av. Jorn. Aníbal Fernandes, s/n - Cidade Universitária
Recife, PE, Brazil 50740-560
abc@cin.ufpe.br

Carlos A. G. Ferraz
Centro de Informática – Universidade Federal de Pernambuco (UFPE)
Av. Jorn. Aníbal Fernandes, s/n - Cidade Universitária
Recife, PE, Brazil 50740-560
cagf@cin.ufpe.br

ABSTRACT

Driving is changing due to more embedded intelligence in cars and to the networking capabilities now rising, making possible that vehicles, infrastructure units, drivers', passengers' and pedestrians' smartphones and any other devices communicate with each other. A smart city can make use of the information available due to the connectivity of these devices to improve several aspects of its inhabitants daily life, traffic being one of the most important. Excess of information, however, can be harmful in a dangerous environment such as transit, where driver's attention is key to the safety of everyone in cars and streets. Given this scenario, we propose researching the use of context-aware systems to identify the proper information to be provided to human drivers without distracting them from the driving activity, or to autonomous vehicles without saturating them with non-important information, thus reducing the processing power needed and improving the latency and quality of decisions made. In order to narrow the investigation, this work will be focused on the Quality of Information (QoI) to drivers and autonomous vehicles.

KEYWORDS

Vehicular Applications, Vehicular Networking, Intelligent Transportation Systems, Context, Quality of Information

1 PROBLEM CHARACTERIZATION

Vehicles are central pieces in modern life. Many cities have grown around and have their current shape due to motorized transportation. While in the past cars were basically mechanical machines, the electronic revolution started embedding microcontrollers even in the simplest vehicles. Now, we have a setting where the driving activity is aided by dozens of onboard computers, and millions of lines of code.

Until recent past, car's computers operated individually, merely exchanging information among themselves. Mostly, those computers were used to critical, safety-related issues. Networks of sensors were deployed in cars, collecting very important information related to the mechanic working of the machine, as well as possibly providing feedback to drivers or even actuating in favor of vehicle occupants in case of life-threatening events.

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Now, we are on a trend of connected vehicles, where computers not only work on specific driving activities but are also focused on passenger's well-being and entertainment. Atzori et al. [3] predicted that different types of vehicles, including not only motorized ones but even bicycles too, would become part of the Internet of Things (IoT), being improved by the ability to communicate with other devices. This vision is now a reality, with affordable new vehicles providing features supported by Internet connection.

Considering the network technology required for this change, intense research and development has been done to enable cars to exchange information among other vehicles - Vehicle to Vehicle (V2V) communication -, with infrastructure devices - Vehicle to Infrastructure (V2I) and with any other device, such as smartphones or gas pumps - Vehicle to Everything (V2X). Technology such as IEEE 802.11p, part of the Dedicated Short Range Communications (DSRC) and Wireless Access in a Vehicular Environment (WAVE) standards, have been developed to address the challenges related to using wireless communication in vehicles, such as the high speed, mobility and frequent topology changes to the network. Vehicular Ad-Hoc Networks (VANETs) have been a topic of study for some time and several simulations and real-world testbeds have been done.

The supporting technology to enable such networks however is not enough. Since autonomous driving is not still widely available or even socially accepted, most features brought by IoT to vehicles have to take in consideration that drivers must be focused on the road and minimize distractions. The concept of ubiquitous computing [27] must be applied, since we need to maximize the outcomes of the processing activities while minimizing interrupting or prompting drivers.

Context aware [8] and context sensitive [25] computing techniques fit in this scenario. Vehicles already have lots of sensors available, and internet connectivity brings even more power to collecting data that can be used to identify the context where the vehicle sits and act accordingly. Formally using context-aware computing approaches on researches related to vehicular networking applications is still not as pervasive as it could have been, given the strength of such techniques. Both academic and commercial researches that emphasizes or focus on the contextual characteristics of their topics are found in small numbers [22].

When considering context-aware techniques applied to vehicular environments, Quality of Information (QoI) is an outstanding factor for the successful use of such tools. In a recent interview to IEEE Pervasive computing [18], Ken Laberteaux, Senior Principal Scientist at Toyota Research Institute-North America, mentions that

QoI has to do with "the right information at the right time". Several data sources can provide information to in-vehicle context-aware systems, and the output of such systems can be sent to multiple different devices, each with its advantages and disadvantages.

Understanding the possibilities of using context-sensitive systems in vehicular applications, contextual information that can be useful in such environment, how they would interact with other systems and the impact of these systems in the stakeholders is the object of this research.

2 THEORETICAL BACKGROUND

This section provides the background required to understand the topics that this research relies on. It is divided into two main topics: Computational Context and Intelligent Transportation Systems.

2.1 Computational Context

It is important to understand the definitions of context for computer applications. Context-aware systems have been discussed in the last years and several definitions exist for such terms.

Abowd and Mynatt [2] determine the five Ws of context as a minimal set of necessary context to context-aware systems. These are the Who, What, Where, When and Why, which categorize some types of information needed by systems using context techniques. From this statement of context based on the types of information, we present the most important definitions of context and context-awareness to computer applications.

Dey [8] establish that context is "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.", and such context is usually related to data about the location, identity and the state of particular entities or groups of entities. Dey goes further and characterizes a context-aware system as one that "uses context to provide relevant information and/or services to the user, where relevance depends on the user's task". This definition of context points that systems can improve their efficiency and user experience by the smart use of contextual information.

Zimmermann et al. [29] enhance Dey's definition and state that "Elements for the description of this context information fall into five categories: individuality, activity, location, time, and relations". Furthermore, they affirm that there are links between some of these categories, such as the connection of time and location as primary generators of relations between entities.

Vieira et al. [25] provide another definition, stating that Context-Aware Systems are limited to knowing what is happening around them, but not necessarily taking actions to adapt to the situation. Then, they define Context Sensitive Systems (CSS), which are "those that manage and use context information to support an agent executing some task, where an agent can be a person or software". This definition clearly distinguishes Contextual Elements from Context. The former are single portions of information that in conjunction with other contextual elements are able to define the Context, which is "the set of instantiated contextual elements that are necessary to support the task at hand".

The CSS definition is more satisfactory for our environment, but the term Context-Aware System is widely accepted to also include the features described by Vieira et al. [25] as Context Sensitive Systems. Hence, this research uses Context-Aware System as a synonym to the CSS definition given by Vieira et al. [25].

Context-aware systems need to handle data from several sources, many of them sensors which reliability and other factors can impact in how much the application can trust and use such data. Castro and Muntz [6] define Quality of Information as a tuple with values of the measurements of accuracy and uncertainty in the most probable value of a variable. Using this definition in context-aware systems leads to the definition of Quality of Context, given by Buchholz and Schiffers [5] as an information describing the quality of information that is also used as contextual information. It is important to note that neither Quality of Information nor Quality of Context are related to the sensors or data gathering methods, they are values that measure the quality of the information provided or context inferred.

2.2 Context Modelling

Bettini et al. [4] discuss requirements of context modelling and reasoning techniques, defining contextual information types and their relationships. Among the requirements, it is stated that contextual models must be heterogeneous, able to deal with information gathered from different sources, in distinct update rates and having a wide range of semantic level. Models should also be able to describe clearly the relationships and dependencies between different types of information.

Chihani et al. [7] summarizes approaches that can be used to model context, from key-value pairs to more complex structures such as XML based languages designed to describe context and be used in runtime. UML-based alternatives are also presented, featuring the advantages of using object-oriented paradigm constructs to model context. Another approach suggested is using ontologies to model context, describing it with OWL (Ontology Web Language), which is based on RDF schema. Ontologies have the advantage of being standard and specific tools to describe elements and their relationships and semantics on a domain, with the possibility of representing complex characteristics and performing consistency checks.

2.3 Intelligent Transportation Systems

IEEE organized the first International Conference on Intelligent Transportation Systems (ITSC) in 1997 [13], however, academic research and industry development of more efficient transportation systems can be traced back to the 1930's[10]. On mid 1990's, the fundamentals of ITS were based strong enough to allow the research and development communities to adopt unified methods, processes and terminology to projects in the topic.

Based on the definitions of Figueiredo et al. [10] and Guerrero-Ibanez et al. [12], it is possible to establish that an Intelligent Transportation System is the application of communication, information and electronics to minimize pollutant emissions, vehicular wear and time spent while commuting, while maximizing fuel efficiency, road usage and safety. Guerrero-Ibanez et al. [12] state that emerging technologies, such as the trend of connected vehicles, cloud computing and the Internet of Things, will shape the future development of ITS.

The development of network standards and technology and the deployment of vehicular networks allowed the start of research on systems that make use of this connectivity. These applications are commonly categorized as Vehicular Network Applications. According to Vahdat-Nejad et al. [22], some of the possible services provided by these applications include collision warnings, road hazards, traffic conditions and points of interest notifications and overtaking assistance. From these types of vehicular network applications and the previously given definition for ITS, we assume that vehicular networks applications are a subset of intelligent transportation systems.

A large number of vehicular network application projects already make use of context-awareness [22]. Furthermore, it is not uncommon to find research like the one performed by Zheng et al. [28], who reviewed usage of Big Data on Social Transportation, that mentions several topics clearly related to context-awareness, but without even using the word "context". A careful researcher in this area must be aware of this fact, because most of the projects related to ITS have some use of computational context gathering and processing. Considering the environment of connected cars, which has a high mobility rate, application designers must also be careful on the architecture they choose to handle context.

Dikaiakos et al. [9] investigate how to develop time-aware services to provide useful information to drivers, such as traffic conditions and nearby road services. They propose an Ad-Hoc network protocol between vehicles and sensors. The results were validated using simulation software, but no real world testbed experiments were conducted.

Seredynski et al. [21] researched using vehicular networks for interconnecting traffic lights and vehicles, allowing the signal lights to adapt to real-time traffic conditions as well as providing feedback to drivers with information of the appropriate speed to drive in order to reach the next stop lights when it is green. Reis et al. [19] found evidence that the efficiency of individual sensors providing their data to vehicles can be improved by aggregating on a contextual-processing device. Their work aims to create this device, to integrate location, climate, traffic lights and camera data to further process and generate new useful information for the transit scenario.

Gerla et al. [11] classify vehicular networks as a subset of the Internet of Things, discussing current technology where cars are sensor platforms, using data available on the environment to generate information that can improve the driving for the driver, to the several systems inside the car and even to other vehicles connected to the network.

Driving attention is the focus of researches both in academic and industry settings. Volvo [23] developed a system for managing the driver's attention based on the behavior of their head and eyes, and measuring face features and temperature. Data is used to generate warnings to drivers to keep their attention on the road and avoid sleeping. Our research could, for instance, build upon this work, using similar data to identify the device which could cause the smaller distraction to the driver receive the system's output.

Saravanan et al. [20] proposed a middleware architectural framework for vehicular safety using contextual data to support the driver on avoiding collisions and identifying critical situations. Drivers behavior and contextual information from several sources are collected and combined to identify critical situations (e.g. imminent accidents). A real testbed experiment was conducted using nine vehicles, but used only one screen. The study did not consider additional risks caused by distractions created to the driver by the system, where almost 30% of the fired alerts were false-positives.

In the scenario of vehicular networks, IEEE 802.11p has been proposed as an amendment to IEEE 802.11 standard to add wireless access in vehicular environments [14]. Furthermore, this standard has emerged to address key concerns in Intelligent Transportation Systems (ITS) applications involving vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) or vehicle-to-everything (V2X) communication [15].

3 OBJECTIVES AND EXPECTED CONTRIBUTIONS

This research aims on offering as the main contribution a model to the assessment of Quality of Information for vehicular applications. Applications for such model are wide, such as: Identification of reliability levels of inferred context situation; Automatic identification of ideal media to use as output to provide information to drivers; .

A byproduct of this research will be an ontology of contextual elements useful for vehicular applications, useful for any application designer who desires to create context-sensitive applications for cars. This ontology will also clearly represent the relationships which are usually present among contextual elements in vehicular application scenarios.

Nonetheless, a systematic mapping of context-aware techniques and applications related to vehicular applications is also a relevant contribution of this research. This mapping will represent the state-of-the art of context-aware techniques applied in the vehicular application domain as of its publication, being useful to other researchers in the area as a summarized reference.

4 CURRENT RESEARCH STATUS

We identified that context-aware techniques are useful for vehicular applications, but both areas seemed not to be frequently researched together. This impression led to the development of a systematic mapping, trying answer questions such as: What has already been done relating Context to V2X? Which were done in real or simulated environment? Who are the key researchers currently working in this area? What are the major trends in the area?

After choosing keywords that could help us in identifying such work, Google Scholar was used to query article databases for works published since 2012 including at least three of the selected keywords. The articles were then filtered to remove unrelated articles which by coincidence had the keywords, and then it was used a year-weighted formula to select top-cited works balanced by their published year. This allowed the inclusion of recent relevant works too. Fifteen works were selected after this pruning.

The selected articles were then read and analyzed. Initially, it was planned to run a reverse snowballing on the fifteen articles, but their content was useful to identify the need for a contextual

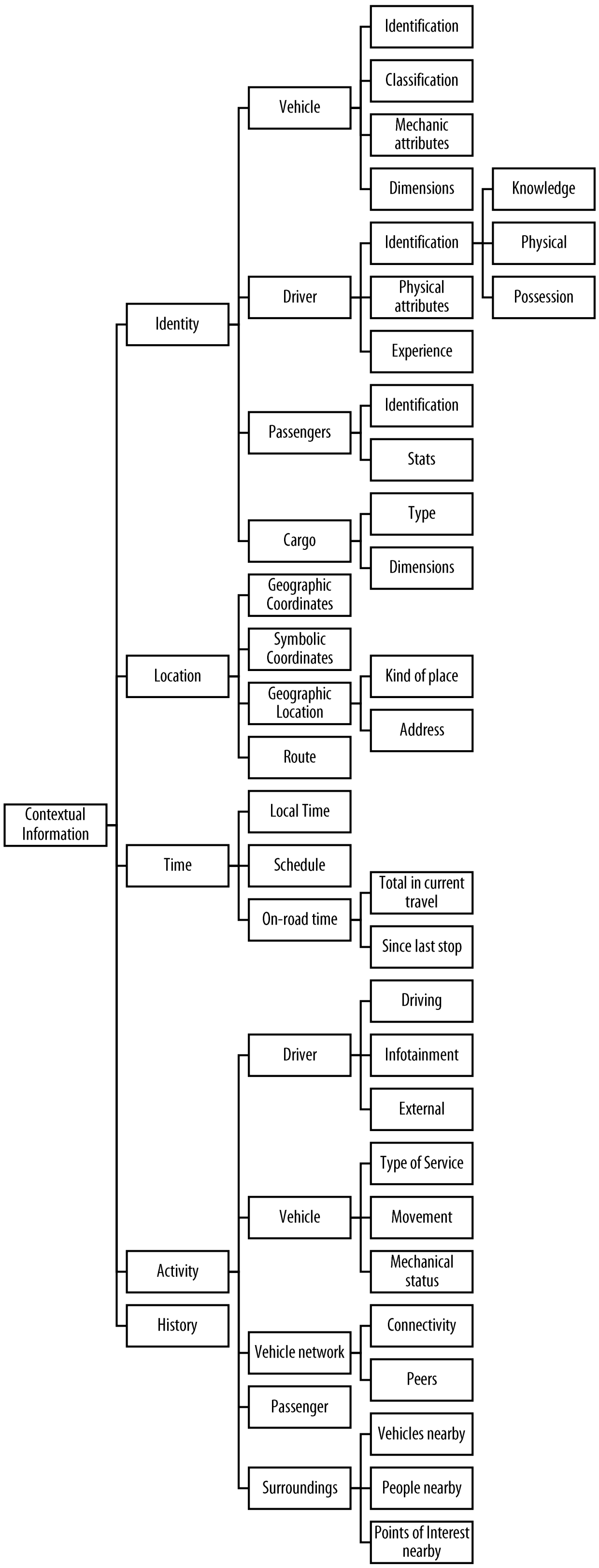

Figure 1: Current status of the categorization model. This model will be the basis to the ontology that will be created.

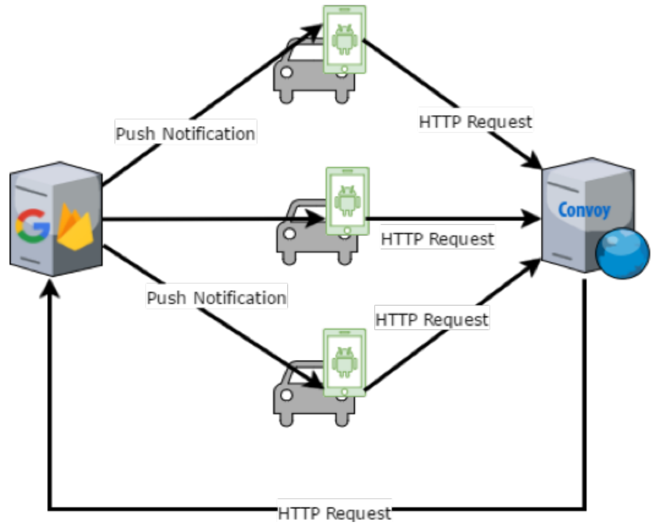

Figure 2: Push-notification based architectural model used used in the developed application

elements model. Several of the analyzed articles mentioned research projects applying context-aware computing on different vehicular applications, each with peculiar needs, but some of them sharing characteristics in the usage of contextual elements.

An initial version of this model was created and is under evaluation. Its current status can be seen in Figure 1. Further work on such model is underway, such as its use on a V2X context-aware application.

When we consider that the model is mature enough and that we have exhausted what can be represented using only the hierarchical-based organization, we will start its evolution into an ontology-based model, allowing a greater representative power to relate contextual elements.

5 DESCRIPTION AND EVALUATION OF RESULTS

Research done up to this moment has generated satisfactory results. The fifteen articles elicited during the first step of the systematic mapping have relevant recent work which is helping to guide this research.

The contextual elements model created is currently very comprehensive and has a strong theoretical base, having been created upon the reports of other research projects. We consider that this model has potential to generate other positive results. We are currently evaluating the current model by developing a context-aware vehicular application that is having its contextual elements chosen using the model as a guide.

The V2X context-aware application being developed has also generated good results. The application itself aims on improving road traveling by vehicle convoys, and relies heavily in its context-aware features to work and improve its results. The development this application also resulted in the proposition of an architectural model based on cloud infrastructure and push notifications for real-time contextual applications, which can be seen in Figure 2.

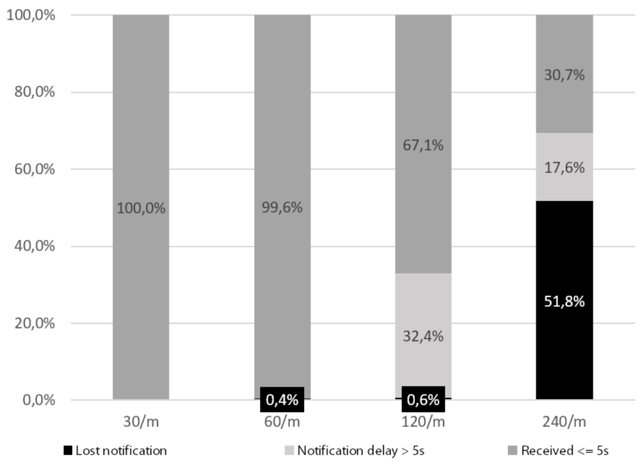

Figure 3: Results of the packet loss and latency analysis of the proposed architecture model

This architectural model has been evaluated in terms of latency and packet loss. Figure 3 contains the results of the evaluation, which pointed that when devices receive up to one notification per minute, almost 100% of the notifications are received correctly, removing a great need of bandwidth to the server. This evaluation reached a positive result indicating the feasibility of the proposed architecture. Also, applying this model in the application resulted in a good user experience.

6 COMPARISON WITH RELATED WORKS

This research is still in initial steps and we still have no specific results to compare with related works. Considering activities that have already begun, we can compare the design of a contextual elements model with other initiatives of creating similar models, either general or specific to other domains. General models as the one provided by Vieira et al. [24] are useful, but specialization to a domain offers advantages to software designers. Models focusing on a specific domain, as the ones described by Mitchell et al. [17] to medical applications or Villegas et al. [26] to web applications reveal the potential of specializing a model to describe contextual elements and their relations when focused on a single domain.

When we focus on the use of vehicle-to-everything communications as means to improve quality of information and context, similar works are scarce. One of the researches relating both concepts is Martuscelli et al. [16], where Quality of Information is considered in the design of protocols used to distribute information in a VANET without using Road-Side Units. Martuscelli et al. [16] shows the potential to use Quality of Information even in lower-levels of vehicular communications, something that is not addressed in this work but is useful to see the wide range of applicability of this area.

Abdelhamid et al. [1] has researched using Quality of Information with V2X. This research defines the concept of Vehicle as a Resource (VaaR), where vehicle's sensors, computing power and data storage can be seen as resources to be used not only by the car itself, but that could also be shared with other vehicles connected to it. Using this concept, quality of information that a vehicle delivers is important and needs to be measured. Validating data, assessing its quality and choosing among sources with different reputation levels is described by Abdelhamid et al. [1] as a challenge and an open issue. This research fits in this open issue, trying to address some of these points, mostly considering the choice of proper sources of data (and outputs of processed state) according to context and quality of information.

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