# A Survey on Context-Aware Vehicular Network Applications

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**Abstract-** Transportation is considered as one of the main human needs in any country for macro-level planning. Due to increased production of vehicles, problems and issues associated with transportation systems have been taken on wider dimensions. Thanks to rapid technological developments, Vehicular Ad-hoc Networks (VANETs) have been used to provide effective opportunities for enhancing the safety of roads and for improving transportation networks. Various context-aware applications have been designed on vehicular ad-hoc networks, offering a wide range of services to drivers, including traffic management, collision avoidance, and convenient supports, just to name a few. This paper reviews and classifies existing context-aware applications as used in vehicular networks. A classification framework with three dimensions including the environment, system-and-application, and context-awareness is proposed. This framework is then used to review the existing context-aware transportation systems for each dimension, which in turn consists of some parameters. Based on this framework, existing context-aware research projects are reviewed and classified. Finally, a clear vision of research directions in this area is described.

**Keywords:** Vehicular Ad-hoc Network, Mobile and Pervasive Computing, Context-Awareness

## 1- Introduction

Vehicles have become an essential part in people's daily lives, despite the inherent problems associated with them (e.g., accidents, pollution, etc.). It is estimated that each year more than 1.27 million vehicular accidents occur across the globe [1], ninety percent of which are attributed to human error [2]. This fact poses serious threats and challenges to the society. Moreover, traffic congestion, due to increased use of cars, leads to fundamental problems, including longer trip times, increased air pollution and huge fuel consumption.

Researchers and industry professionals have used information and communication technologies in the transportation area under the title of Intelligent Transportation Systems (ITS) [3]. In light of recent developments in computational and communication technologies, many researchers have become attracted to the new field of context-aware vehicular ad-hoc networks as a technique to provide proper solutions to transportation system challenges.

The Vehicular Ad-hoc Network (VANET) is a branch of the Mobile Ad-hoc Network (MANET) and a component of the intelligent transportation system that have emerged thanks to advances in the wireless technology and automobile industry [4-7]. However, various reasons such as high mobility as well as driver behavior and decisions dramatically distinguish the VANET from the MANET [8]. VANETs have unique characteristics such as high mobility, high computational ability, rapid changes in network topology, and variable network density [9].

Over the past years, several research papers have focused on proposing communication protocols for VANETs [10]. As a result, various wireless solutions for vehicle-to-sensor, vehicle to-vehicle, vehicle-to-Internet, and vehicle-to-road have been developed [11]. Today, the vehicular ad-hoc network provides the required infrastructure for a wide range of context-aware transportation applications including safety, the improvement of traffic state, and drivers' convenient supports. In these networks, real-time traffic monitoring, traffic sign warnings, recognition of passengers, barriers, and road lanes, accident detection, and speed and distance estimation provide drivers with better decision making abilities. Among other applications of these networks are automatic payments of parking fees and highway tolls, multimedia communication, and access to the Internet. With VANETs, the vehicle or driver's "horizon of awareness" increases intensely [12]. In general, context-aware applications of vehicular ad-hoc networks use driving context information to adapt various decisions according to the environment situation. These applications are able to sense, reason, and react to the environment. The key feature of them is *"context-awareness."*

Due to the importance of VANETS to research community, several survey papers have been published recently. Most of these papers investigate VANETS from a communication viewpoint [3, 9, 13-15]**.** However, the scientific literature lacks a comprehensive survey from the application viewpoint. The main distinction of this paper from other surveys is the focus on the application layer as well as context-awareness. Reviewing and classifying context-aware applications of transportation network can help with the development of future research studies in this field. We propose a classification framework with three dimensions including environment, system-and-application, and context-awareness wherein each dimension consists of one or more parameters. Then, based on the proposed framework, context-aware applications in vehicular networks are classified from a technical perspective.

The environment dimension describes the domain assumed about the vehicular network applications, such as urban, rural, and highway environments. The system-and-application dimension consists of several parameters including the service type, system architecture, communication type, and application action pattern. The service type refers to the type of services and advantages provided by vehicular network applications such as safety, traffic management, and support for drivers. The system architecture indicates the structure of system components on the vehicular network. Some vehicular network applications have a centralized architecture, meaning that all operations of the application are performed on a central main server. In some other applications, the main component of the system is distributed on a set of servers, forming a distributed architecture. Vehicular communication refers to the wireless communication mechanism used in the applications of the vehicular network. Communications can take place directly among moving vehicles in vehicle-to-vehicle (V2V) form or between vehicles and fixed road-side equipment. The Action pattern characterizes the way in which the application is executed and performs action on the vehicular network. Vehicular ad-hoc network applications are executed in different modes such as event-based, periodical, or based on user demand.

The context-awareness dimension consists of the two parameters of context type and context gathering method. Context-aware vehicular network applications make use of such driving context information as speed and acceleration of the vehicle, traffic information, and weather information, among others. These applications build on different technologies like on-board sensors and devices, road-side infrastructure, internet infrastructure, among others to collect driving context information. We aim to provide a comprehensive understanding of context-awareness in vehicular network applications.

This paper is organized as follows: After this introduction, related background information including pervasive computing, context-awareness, and context-aware vehicular network are described in Section 2. In Section 3, a framework is proposed for classifying context-aware applications in vehicular networks. Section 4 describes the existing research projects in vehicular networks. Sections 5, 6, and 7 review and classify the projects according to the criteria of the proposed framework. Finally, concluding remarks and open research directions in this area are discussed in section 8.

## 2. Background

Pervasive computing and ubiquitous computing are used interchangeably in the literature. It was Mark Weiser who firstly expressed his vision about pervasive computing in 1991: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" [16]. From the perspective of Weiser, in the era of pervasive computing, the presence of computing services is often overlooked, due to their widespread and vital roles in people's daily activities. In fact, pervasive computing environments are saturated with computing and communication capabilities, and have integrated with users in such a way that it seems like an invisible technology [17].

Mark Weiser introduced ubiquitous computing as the third wave of computing technology [18]. The first wave refers back to the era of mainframe computing, wherein many people used to share a single computer. The second wave came with personal computers, allowing each individual to have their own computer. In the era of ubiquitous computing, however, many computers of different types could be shared for each person, which provides the user with a set of personalized services. Mark Weiser has predicted a transition from personal computers and distributed computing to pervasive computing during 2005 to 2020.

Pervasive computing aims to create a world in which objects have computational and processing abilities, communicating with the global network through wireless or wired links. Here, any person can automatically receive personalized services from computers that have been embedded in the surrounding environment and that are invisible from their sight.

In the past decade, advances in hardware technologies have given rise to complex and small computational devices, which can provide infrastructure for pervasive computing. Through integrated connection of several information devices embedded in the user's environment, pervasive computing attempts to be aware of the user situation and his/her environment and to adapt services/actions accordingly [19].

Applications run within a pervasive computing environment are executable and available to users at any time and place. Instead of receiving inputs from users as in traditional methods, these applications sense the context information implicitly from the environment and perform the proper action accordingly. These applications, which are known as "context-aware", form the building blocks of pervasive computing [20, 21].

### 2-1 Context-Awareness

Context is a fundamental concept in pervasive computing environment. Context has several definitions [22-24]; However, in a consensus definition, it is defined as "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 [25, 26]". "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task [25, 26]".

In the pervasive computing environment, context-aware systems use context information related to the user, at any time and any place, to adapt their operations to the environmental situation. In fact, context-aware applications are applications that are capable of adapting their operations to the user's context, which is provided by sensing the environment contextual information [27]. In general, the development of any context-aware application consists of the following three main components [21, 28]:

- **Context acquisition:** gathering contextual information by sensors.
- **Processing:** employing reasoning techniques in order to obtain high-level contextual information (such as user’s activities).
- **Acting:** providing services to the user according to his/her current situation.

### 2-2 The Context-Aware Vehicular Network

Recent advances in software, hardware, and communication technologies have facilitated the design and implementation of various network types in different environments. One network that has attracted great interest in recent years is the vehicular ad-hoc network [13]. VANET is a specific term used to describe the self-organizing ad-hoc network of moving vehicles [29]. Vehicular network is a kind of mobile computer network in which vehicles act as computer nodes connected in a network through inter-vehicle communication. In the vehicular networks, vehicles are equipped with computation and wireless communication devices that can communicate with each other and with road-side units. These communications allow vehicles to share the driving contextual information including safety information (e.g. hazardous situation of driving) to prevent accidents or non-safety information (e.g. weather conditions, tourism and traffic information) [9].

In context-aware vehicular networks, any information that describes the driving situation is called driving context information [30]. The information such as the position, direction, speed, and acceleration of the vehicle, traffic and weather information, among others are part of the driving context information.

In the vehicular network, driving context information always changes dynamically. Context-aware applications in the vehicular network are capable of adapting their operations as a response to the change of driving context information. These applications are constantly aware of the driving situation and road condition, and are adaptable to the changing driving environment.

In the context-aware vehicular network, the driving context information is gathered through sensors and vehicle communication capabilities. The driving environment state is reasoned based on the available context information, and appropriate services are provided for the vehicle accordingly. For example, in intersection collision avoidance application [31], the context information of vehicles approaching the intersection such as speed, position, and acceleration are gathered and processed. As soon as the possibility of a collision is detected, a warning is sent to the approaching vehicles to prevent the collision.

## 3- The Proposed Framework

Given their unique characteristics in the development of intelligent transportation systems, vehicular ad-hoc networks have been considered as an important research field [5, 9]. Vehicular ad-hoc network supports a variety of context-aware transportation applications. In this paper, these applications are reviewed and classified from the perspective of three dimensions including environment, system-and-application, and context-awareness. Figure 1 shows these dimensions as well as their parameters. In this section, the proposed reviewing framework is described. Later, in Sections 4, 5, and 6, available research projects are surveyed and classified according to each of these dimensions, respectively.

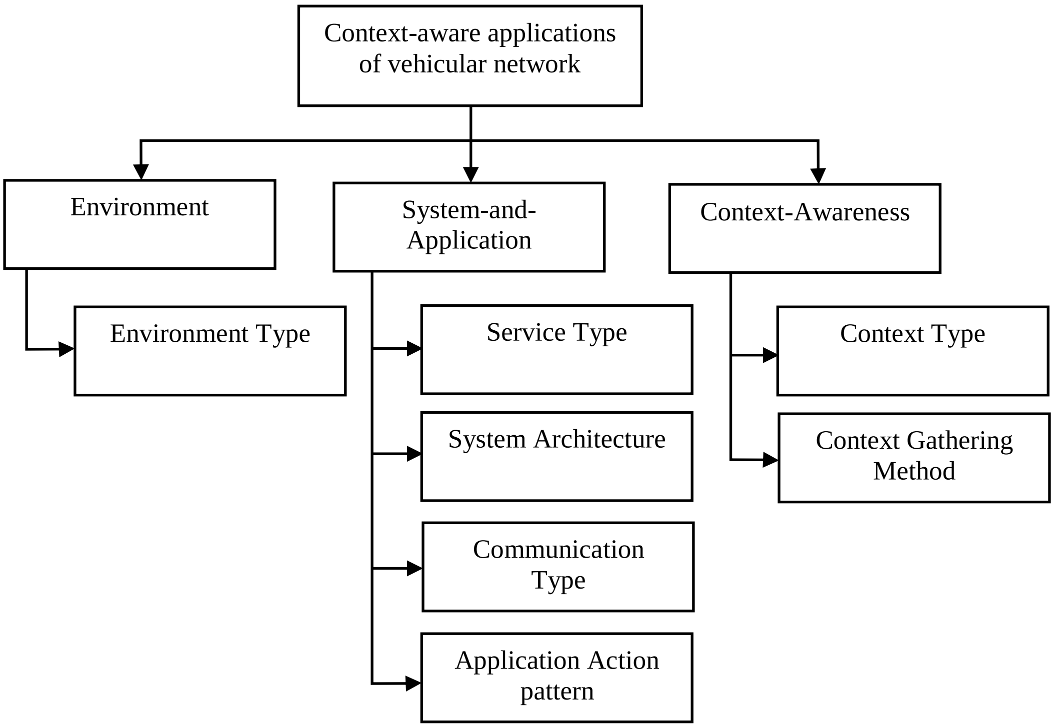


**Figure 1: The proposed reviewing framework**

### 3-1 Environment

This dimension involves the type of environment for which the context-aware application is designed, implemented, and deployed. In general, a typical application in this domain is designed for a particular environment such as urban, rural, and inter-city highways. Different environments have different characteristics, some of which are mentioned below:

- Context information has different impacts for various environments. Besides, required services are different. For example, while traffic management can be a main concern in an urban area, collision avoidance may be of more concern in inter-city highways.

- Values and characteristics of contextual information are different for various environments. For example, traffic congestion in an inter-city highway is different from an urban environment. The traffic is usually low in a typical inter-city highway, whereas in urban areas, it faces complicated conditions due to the vast number of cars and intersections. Besides, an urban area includes traffic lights and surveillance cameras in order to control traffic, while highways are devoid of these and make use of loop detectors to measure traffic.
- In any area, there are certain traffic rules and regulations. For instance, the speed limit in an inter-city highway is higher than that of urban and rural environments.

### 3-2 System-and-Application

The system-and-application dimension consists of a set of parameters including service type, system architecture, communication type, and application action pattern. In the following, the parameters are introduced in detail.

#### 3-2-1 Service Type

This parameter specifies the type of service and advantage that the application provides. Context-aware vehicular ad-hoc networks have provided the feasibility to develop a wide range of transportation applications including safety and non-safety ones. Among them are the followings:

- **Collision warning:** These systems monitor the driving environment and warn the drivers as soon as the possibility of a collision is detected [9].
- **Road hazard condition notification:** Upon detecting hazard conditions of the road such as a hill, road curve, roadwork, and presence of snow and ice on the road surface, the vehicle notifies other vehicles close to the hazard area [3].
- **Approaching emergency vehicle warning:** This kind of system helps specific vehicles such as ambulances, fire-fighting or police vehicles to reach their destination without waiting in traffic. This is usually achieved through dissemination of alarms by emergency vehicles to the nearby vehicles to open the path [9].
- **Overtaking assistant:** The system monitors traffic conditions and provides an appropriate mechanism to prevent collision during overtaking and maneuver. At the time of decision-making for changing lanes, this kind of application evaluates the situation by collecting and processing contextual information about the vehicle as well as nearby vehicles, and guides the driver concerning the right moment to overtake [32].
- **Traffic condition notification:** The vehicle can be notified about the traffic state for a better travel plan by communicating with a traffic control center or other vehicles [33, 34].
- **Point of interest notification:** The application provides information about locations of interest such as parking lots, gas stations, hotels, or restaurants place to the driver [3].

#### 3-2-2 System Architecture

System architecture is “the structure of the components of a program/system, their interrelationships, and principles and guidelines governing their design and evolution over time” [35]. In order to determine the system architecture, its main component should be identified. If this component is designed centrally on a single computer, the system is called *centralized*; otherwise, it is called *distributed*. In a centralized system, the failure of the server causes failure or disorder of the functionality of the entire system.

### 3-2-3 Communication Type

The VANET allows vehicles to communicate directly with each other, known as vehicle-to-vehicle communication (V2V). Also, vehicles can communicate with road-side units via vehicle-to-infrastructure communication (V2I) [36, 37]. These vehicular communications make use of various wireless technologies such as cellular systems, WLAN/Wi-Fi, WiMAX, DSRC (Dedicated Short Range Communication), among others [9]. Usually, V2V communication supports short and medium range, and V2I communication supports a wide range [29]. Nonetheless, V2V communications with multi-hop capability can cover a wider range.

These vehicular communications allow the drivers to communicate with nearby nodes such as neighboring vehicles, sensors and road-side signs, as well as infrastructure servers. In fact, these wireless communications increase a driver's perception by linking her with the surrounding physical environment. In general, Context-aware vehicular applications may utilize any of the vehicular communication types.

### 3-2-4 Application Action pattern

This parameter specifies how the system responds when certain context changed. Vehicular network applications run according to certain patterns. Some applications act when a certain event happens. For example, as soon as the risk of a collision is detected in the collision avoidance application, it warns the driver or automatically sends order to press brake pedal to prevent collision. On the other hand, points of interest notification applications act upon request by users.

## 3-3 Context-Awareness

Vehicular applications sense the driving context and share this information between vehicles and road-side infrastructure through communication technologies. In other words, they are context-aware. The context-awareness dimension consists of two parameters: “context type” and “context gathering method”, which are discussed below.

### 3-3-1 Context Type

Transportation applications utilize different types of contextual elements. Information about the position, speed and acceleration of vehicles as well as streets' traffic are among the most highly applied pieces of context. Previously, several categories have been proposed for the types of context information. Ryan et al. categorize context types into location, environment, identity, and time [38]. Schilit et al. list context types as where you are, who you are with and what resources are nearby [23]. Abowd and Dey have proposed the most important types of context as location, time, identity and activity, and called them the primary context. These primary context types can be used as index to obtain secondary context information. For example, if we have a user's identity, we can obtain information about her phone number, address, email, friends' list, and so on [26].

In the transportation domain, context is generally defined as the information describing the driving situation. Information about the driver, vehicle, environment, traffic regulations, and related factors are part of the transportation contextual information [30]. In light of the fact that transportation is a specific area with its unique characteristics, these general categorizations are not suitable. The proposed classification is explained in section 7.

### 3-3-2 Context Gathering Method

How to gather the driving context required for applications is an important issue [39]. Recently, types of driving context information such as speed, acceleration, and location of the vehicle, traffic information, and road conditions are available for applications, thanks to the hardware advances of sensors and technologies. Vehicles are equipped with different sensors through which they can obtain their required context information.

The context-aware vehicular network provides the ability to gather, process, and disseminate the driving context by integrating on-board devices and vehicle sensors with the road-side infrastructure through communication technologies.

## 4- Prominent Context-Aware Projects

Along with the significant advances in context-aware systems and VANETs, some projects have performed on these new technologies in order to address transportation problems. This section focuses on providing a general overview of prominent research studies concerning context-aware applications in vehicular network. The projects are briefly introduced and later summarized in Table 1. Because this introduction is general and the proposed reviewing framework is from three computer science viewpoints, we have not provided these general parameters in the proposed framework.

- **On-Street-Parking [40]:** This project has been designed by De Montfort University of United Kingdom and presents an on-street parking system. It uses the concept of Information Stations (IS) and context-aware systems for locating and reserving parking spaces. The project aims to provide more convenient and more efficient parking reservation in order to prevent unnecessary and time-consuming delays at the time of locating a parking space, and avoid fuel consumption and decrease pollution of the environment. In this system, each parking zone has a specific InfoStation, which provides wireless coverage for that zone. Parking zones are distributed according to street names, and one InfoStation Center (ISC) monitors and coordinates all InfoStations . Here, vehicles send a parking request message to the local InfoStation installed on the side of the street. Then the InfoStation locates and reserves a parking space on the basis of available parking spaces and the position of the vehicle.
- **TOCADAS [41]:** TOlerant Context-Aware Driver Assistance System (TOCADAS) has been designed in Catholic University of Daegu with an aim to prevent collisions and reduce traffic damages. In this project, a driver assistance system as a brake actuator is designed, which reasons the current driving situation by gathering context information about the vehicle and the driving environment, and prevents collision as soon as a hazardous situation is detected.
- **CADAS [42, 43]:** Context-Aware Driver Assistance System (CADAS) has been developed by Acadia University in order to avoid collision and improve driver's reaction time. This system combines the five advanced functions of lane keeping assistance, forward collision avoidance and speed adaptation, blind spot detection, intersection coordination, and traffic signs recognition to provide an integrated system for collision avoidance. In order to demonstrate the feasibility of the system, it has been simulated on lego mindstorms NXT [44] robots environment.
- **Road-Accident [45]:** This project has been designed in Amrita University with an aim to detect and locate road accidents in real time and notify the end users in order to save the lives of victims. This system is composed of three main modules: onboard sensor system, participatory sensing part, and monitoring center. The onboard sensor system includes a set of sensors on the vehicle to detect vehicle accident and send alarm to the monitoring center. The participatory sensing part

includes other vehicles devices as well as smartphones of available persons around the accident. Smartphones sense the abnormal huge sound of the accident and notify the monitoring center. In fact, this part is integrated with the onboard sensor system to validate the gathered information and reduce false alarms. Finally, the monitoring center sends the accident message to the end users on the basis of the received messages from the participatory system and the crashed vehicle. This system has been simulated for different accident scenarios in proteus platform.

- **DBD [46]:** Context-aware Driver Behavior Detection system (DBD) has been developed in De Montfort University to detect abnormal behavior of the driver. The system collects contextual information about the driver, the vehicle's state, and environmental changes and reasons the driver behavior as a high-level context. This system is able to detect four driving behaviors including reckless, drunk, fatigued, and normal. Upon the detection of the driver's abnormal behavior, it warns the driver and nearby vehicles to prevent accidents.
- **CAGFP [47]:** Context-Aware Geocast Forwarding Protocol (CAGFP) is co-developed in Urmia University as part of the CVT (Connected Vehicle Technology) project at Sharif University of Technology. It aims to develop a data dissemination mechanism for timely and reliable notification about an accident to nearby vehicles in order to prevent chain accidents. In this system, each vehicle maintains its local topology (i.e., a list of neighbors in its transmission range). When an accident occurs, it creates a notification packet and broadcasts it in the surrounding topology. This project has been simulated in a four-lane unidirectional highway using Veins Simulator Framework.
- **Electric-Vehicle [48]:** Researchers in University of Bradford have developed a route planning system for fully electric vehicles in order to optimize their energy consumption. The motivation of the project is the limited battery capacity and time-consuming recharge of electric vehicles. The system offers an optimal dynamic route from the start point to the destination in order to plan the travel for electric vehicles. It is based on contextual information including real-time traffic data, road length, road slope, and estimates the route cost and offers the route with the least travel time and energy consumption. In case there is too low energy to reach the destination, the system suggests an optimal detour according to the recharge points. The system has been simulated using SUMO simulator on the road network of Bradford.
- **Overtaking [49, 50]:** This project has been developed by University of Klagenfurt and offers a context-aware overtaking assistance system. It utilizes a constraint-logic approach in order to consider all legal and environmental constraints of overtaking maneuver. The system uses information related to oncoming and approaching vehicles, traffic signs, road condition, the current state of the driver, and other constraints of overtaking, and recommends a desirable time and speed for overtaking. The reasoning component of this system has been simulated on ECLiPSe constraint programming environment.
- **Gas-Station [51]:** Researchers in Technical University of Munich have designed a context-aware gas station recommender system in order to suggest the closest cheap gas station. Using current context and the user's profile information, the system suggests cheap gas stations located in the vehicle's range. In other words, this application involves two stages: (1) determining all the gas stations within the range by an analysis of the route, amount of fuel and the distance that the vehicle can travel with its current fuel, and (2) ranking the retrieved gas stations in terms of price, user preferences, and whether the user wishes to choose a detour or not.
- **IDB [52]:** A large number of accidents occur as a result of the drivers' behavior and wrong decisions at critical moments of driving. Researchers in Acadia University have developed an Improving Driver's Behavior system (IDB), which links the driver to the physical environment using the contextual information obtained from sensors and cameras embedded in the vehicle. The

application provides an alarm system to warn the driver and help her to decide better under critical situations. This system has been simulated by Lego Mindstorm NXT robots.

- **CAISA [53]:** Since high speed brings about a potential for the occurrence of accidents, researchers in Delft University of Technology have developed a Context-Aware Intelligent Speed Adaptation system (CAISA). The system aims to bring more safety in traffic, decrease fuel consumption, and reduce greenhouse gases. This system has been implemented and tested in the Dutch cities of Leiden, Katwijk aan Zee, Katwijk aan deRijn, Voorschoten, Zoeterwoude, and Leiderdorp.
- **CFMS [54]:** Accidents are unplanned events that occur at an unpredicted place and time. An accidents lead to a significant reduction in the capacity and increase in the traffic load of the road segment where the accident has occurred. An important issue in fleet management concerns the optimization of vehicle scheduling at the time of accidents. After an accident, re-scheduling is very difficult because of the large number of vehicles and daily travels. In this context, the researchers at Hong Kong Polytechnic University have developed a Context-aware Fleet Management System (CFMS) for instant management of the fleet. The system can provide an optimal re-scheduling in case there is an accident or delay in vehicles' travels.
- **InCarMusic [55]:** This project has been developed by University of Bozen-Bolzano. It presents a system that can suggest music tracks to the driver according to the traffic conditions and the driver's mood and preferences. It requires the acquisition of the tracks' ratings under different circumstances. Therefore, it is necessary to take into account the personal perceptions of the users concerning the effects of context information on their decisions in order to facilitate the rating acquisition process. After rating the tracks, the system announces to the passengers the recommended items proportionate to the context information. In case the user has not already entered any rating, music tracks will simply be suggested according to the context information, irrespective of the user's preferences. When a music track is played, the user can rate it; The system collects these ratings based on the current contextual situation and makes use of them in later contextual situations and reasoning. This system has been implemented in the form of a web application.
- **TCE [56]:** Context-aware Traffic Congestion Estimation system (TCE) is developed in Monash University and the Thai Meteorological Department to estimate real-time traffic state for sensor-less road segments or for occasions when the data from mobile sensors is not available. The project has been implemented and tested in Bangkok.
- **CAPM [57]:** Constructing more parking spaces is difficult and costly in the majority of cities. This issue, combined with the inefficient use of available parking spaces, leads to heavy traffic. Research studies indicate that 28-45% of the traffic congestion in urban areas results from the drivers' search for vacant parking spaces [58]. Context-Aware Parking Management system (CAPM) has been performed in the framework of FP7 BUTLER project, which is partly funded by the European Union. It includes a solution based on the Internet of Things (IoT) to monitor and signalize the state of availability of each parking space. It also uses the context information generated by citizens to respond accurately to drivers' demands. The system improves the management of parking resources and allows for the handling of parking space groups. The system assumes four states for a parking space including available parking space, reserved parking space, in-use parking space, and load/unload parking space for quick delivery of goods. In this system, different levels of access are considered depending on the role of the user. Therefore, two main interfaces have been developed, one for drivers and the other for traffic monitoring authorities. Besides, the system involves two operational modes – onsite reservation and online reservation – where the interaction between the user and the server depends on the selected

operational mode by the user. This system has been implemented on FreeRTOS platform which is an open RTOS (Real Time Operating System) for embedded devices.

**Table 1: Overview of context-aware projects in the vehicular network**

| Project Name | Organization | Paper Type | Year | Project State |
|---|---|---|---|---|
| **On-Street-Parking [40]** | De Montfort University, UK | Conference | 2012 | Designed |
| **TOCADAS [41]** | Catholic University of Daegu, South Korea | Conference | 2010 | Designed |
| **CADAS [42, 43]** | Acadia University, Canada | Journal | 2012, 2013 | Simulated |
| **Road-Accident [45]** | Amrita Center for Wireless Networks and Applications, Amrita Vishwa Vidyapeetham, India | Conference | 2013 | Simulated |
| **DBD [46]** | Software Technology Research Laboratory, De Montfort University, UK | Journal | 2013 | Simulated |
| **CAGFP [47]** | CVT(Connected Vehicle Technology) project at ACECR-Sharif Branch under Contract with the IDRO, Urmia University, Iran | Conference | 2013 | Simulated |
| **Electric-Vehicle [48]** | European Union Seventh Framework Programme under EcoGem Project, University of Bradford, UK | Journal | 2013 | Simulated |
| **Overtaking [49, 50]** | Alpen-Adria-Universität Klagenfurt, Austria | Conference | 2008 | Simulated |
| **Gas-Station [51]** | Technical University of Munich, Germany | Workshops | 2007 | Designed |
| **IDB [52]** | Acadia University, Canada | Journal | 2012 | Simulated |
| **CAISA [53]** | Delft University of Technology, Netherlands | Conference | 2012 | Implemented |
| **CFMS [54]** | The RGC of the HKSAR, The Hong Kong Polytechnic University, China | Journal | 2012 | Implemented |
| **InCarMusic [55]** | Free University of Bozen-Bolzano, Italy | Journal | 2011 | Implemented |
| **TCE [56]** | National Electronics and Computer Technology Center (NECTEC) and the Thai Meteorological Department, Monash University, Australia | Conference | 2009 | Implemented |
| **CAPM [57]** | Performed in the framework of FP7 BUTLER project, which is partly funded by the European Union, Spain | Workshop | 2013 | Implemented |
| **CATE [59]** | Pervasive & Cloud Computing Lab, University of Birjand, Iran | Conference | 2014 | Simulated |
| **IR-CAS ACN [60]** | Electrical & Computer Engineering, University of Waterloo, Canada | Journal | 2014 | Designed |

- **CATE [59]:** Context-Aware Traffic Estimation system (CATE) is developed in Pervasive & Cloud Computing Lab at University of Birjand. The project aims to estimate traffic congestion in a way usable by navigation systems to improve travel efficiency. The system makes use of fuzzy logic mechanism to locally estimate traffic state. The fuzzy system utilizes vehicular contextual information including average speed and Mean Absolute Acceleration (MAA) of the vehicle to measure traffic congestion level. The system has been simulated using SUMO simulator for different traffic congestion scenarios in a two-lane highway environment.

- **IR-CAS ACN [60]:** This project is designed at the university of Waterloo. It proposes a crash notification service, which notifies nearby vehicles as well as emergency response teams upon detecting an accident. The project is an enhancement to the BMW Advanced ACN (AACN)[61]. It tries to automatically estimate accident severity in the interval 0 (no accident) to 100 (the most severe accident).

## 5- Prominent Projects Review: Environment

After reviewing the environment of existing context-aware applications in vehicular network, we propose the following classification. This classification categorizes applications into three groups according to the type of environment:

- **Urban:** It includes applications developed to act in urban environments. An urban environment is known by streets, squares, and intersections which faces drivers with different routes. This environment also involves low speed limit and high traffic volume.
  On-Street-Parking, Electric-Vehicle, CAISA, TCE, and CAPM projects are developed for the urban environment. CAISA system has been tested in the Dutch city of Leidenand neighboring cities, TCE system in Bangkok, Thailand and Electric-Vehicle system in Bradford, U.K.
- **Regional:** This environment describes a geographical area like a province or state. Therefore, it includes inter-city roads and highways. Of the characteristics of this environment is the relatively low traffic.
  Among the investigated projects, only Road-Accident system has been developed for the regional environment.
- **General:** It covers context-aware applications that are applicable to all environments such as urban, rural, and inter-city environments, and are not limited to a specific range or conditions. Most projects have been developed for a general environment. TOCADAS, CADAS, DBD, CAGFP, Overtaking, Gas-Station, IDB, CFMS, InCarMusic, CATE, and IR-CAS ACN projects are applicable to various environments and are among these applications.

Table 2 summarizes the reviewed projects in terms of type of the environment.

**Table 2: Environment type of context-aware applications in vehicular network**

| Project Name | Environment | | |
|---|---|---|---|
| | Urban | Regional | General |
| On-Street-Parking [40] | √ | | |
| TOCADAS [41] | | | √ |
| CADAS [42, 43] | | | √ |
| Road-Accident [45] | | √ | |
| DBD [46] | | | √ |
| CAGFP [47] | | | √ |
| Electric-Vehicle [48] | √ | | |
| Overtaking [49, 50] | | | √ |
| Gas-Station [51] | | | √ |
| IDB [52] | | | √ |
| CAISA [53] | √ | | |
| CFMS [54] | | | √ |
| InCarMusic [55] | | | √ |
| TCE [56] | √ | | |
| CAPM [57] | √ | | |
| CATE [59] | | | √ |
| IR-CAS ACN [60] | | | √ |

## 6- Prominent Projects Review: System-and-Application

In this section, we review the projects from the system-and-application viewpoint. This dimension consists of four parameters, which are investigated in the following subsections.

### 6-1 Service Type

Vehicular network applications involve a wide range of services from safety to entertainment and convenience. After surveying prominent projects, we propose three major categories for the service type including safety, traffic management, and convenience and entertainment, which are described below:

- **Safety:** These applications focus on improving safety and preventing accidents. They constantly monitor the driving environment and prevent accidents by notifying the driver of hazardous points on the road or by warning at hazardous situations.

  Service types of the surveyed applications are shown in column 2 of Table 3. Because of the importance of safety, most projects have focused on this service category. From among the studied projects, TOCADAS, CADAS, Road-Accident, DBD, CAGFP, Overtaking, IDB, CAISA, and IR-CAS ACN systems have considered the safety service.

  TOCADAS system monitors the vehicle and the driving environment through gathering contextual information; whenever the risk of collision is detected, it prevents collision by triggering the press of the brake pedal. Besides, CADAS system integrates the functions of lane keeping assistance, forward collision avoidance and speed adaptation, blind spot detection, intersection coordination, and traffic signs recognition to detect hazardous driving situations. In this system, if a positive response is received from any of the hazard detection functions, a warning is sent to the driver to avoid collision.

In Road-Accident system, the vehicle accident is detected by a set of sensors on the vehicle such as accelerometer, gyroscope, and flex sensor, and then notified to the monitoring center. The monitoring center will later notify the location of the accident to the nearest police station, ambulance, and other rescue forces. Subsequently, they initiate the rescue and management procedure. On the other hand, DBD system focuses on the driver and reasons his behavior by gathering contextual information concerning the driving environment, e.g., speed and acceleration of the vehicle, position of the vehicle between lane markers, state of the driver's eyes, and the level of alcohol in the driver blood. The system warns the vehicle's driver upon the detection of abnormal behavior, and also sends corrective actions to neighboring vehicles based on their current position, direction, and speed.

In CAGFP system, the crashed vehicle creates a notification packet about the accident and broadcasts it to the surrounding topology at 0.5 second intervals in order to prevent a chain crash. The Overtaking system builds on the available contextual information concerning the vehicles participating in the overtake maneuver to create appropriate recommendation for the driver and prevent collision between vehicles.

IDB system gathers different context information from the surrounding areas by cameras and sensors. The information is processed on machine and if required the driver is alerted in order to prevent crashes. In another work, CAISA system uses the speed and location as well as the map of the area in order to regulate the engine revolution according to the area speed limitation.

After detecting an accident, IR-CAS ACN estimates the severity, and sends it together with the vehicle and driver information to nearby vehicles as well as RSU. Subsequently, RSU notifies emergency response teams as well as driver's family.

- **Traffic Management:** These applications try to manage traffic by obtaining, sharing, and deciding upon traffic information. In fact, the main purpose is to optimize traffic flow, avoid traffic-making situations, and reduce travel time in the transportation network.

  Few projects have focused on traffic management. Among the reviewed projects, Electric-Vehicle, TCE, and CATE systems consider traffic management. Electric-Vehicle system is based on real-time traffic information and finds out a route requiring the least travel time and energy cost for electric vehicles. In this system, vehicles act as sensors to measure the traffic level and share real-time traffic data by communicating with each other.

  TCE application provides an approach to calculating the real-time traffic state of sensor-less road segments or occasions where mobile sensors' data are not available. This approach builds on combining context information and reasoning over them. To do this, the system uses the previous traffic information as well as the contextual information including weather, time of the day, day of the week, workday, and school break for reasoning the traffic state.

  CATE system exploits a fuzzy logic mechanism to estimate local traffic congestion. The system, which is installed on the vehicle, continually measures the contextual information of vehicle including average speed and Mean Absolute Acceleration (MAA). Afterward, it estimates the local traffic congestion level based on this contextual information. The average speed and mean absolute acceleration of vehicle on a road segment are measured using speed sampling by GPS at constant intervals.

- **Convenience and Entertainment:** This service aims to provide welfare and entertainment facilities as well as business activities for the drivers and passengers. It generally aims to provide convenience and improve quality of travel.

  On-Street-Parking, Gas-Station, CFMS, InCarMusic, and CAPM provide convenience and entertainment service. In On-Street-Parking system, the moving, while moving towards destination, can reserve a parking space,. For this, it sends a parking request message containing the vehicle's profile (i.e. its size and type), the driver's profile, (i.e., her name, license number, and medical condition), parking preferences (i.e. free or chargeable parking), parking destination, and parking duration to the InfoStation installed on the road-side. The InfoStation processes the request message and compares it with the parking's policies (e.g. the parking is only for small or heavy vehicles or it only serves certain people, etc). Then, it locates and reserves a parking space according to the available information and the vehicle's position.

  CAPM system also addresses parking issue in two operational modes: onsite reservation and online reservation. However, the overall procedure is the same. The user sends a request to the server for a list of available parking spaces in a certain location. Upon the server's response, the user selects a space and sends her reservation request to the server. The server subsequently processes the request and if valid, it sends a confirmation message to the user to pay the fee. In occasions when the user wants to reserve the parking space before she reaches the destination, she should set the required parking duration and the start time.

  Gas-Station system suggests cheap gas stations in the driver's range using the current context information such as the vehicle's route, the available fuel, the remaining range (distance that the vehicle can travel with its current fuel), as well as the user's profile information. In another work, CFMS system manages the travels of the fleet vehicles using the context information gathered by GPS, eSeal (Electronic Seal), and mobile devices. It re-schedules the travels of the fleet vehicles when there is an accident or delay in travel. On the other hand, InCarMusic system suggests appropriate music to the passengers according to the user's ranking of the music tracks, and such context information as traffic state, weather conditions, mood and preferences of the driver, among others.

### 6.2 System Architecture

From the viewpoint of structure of the system architecture, the projects are classified into the following categories, which are summarized in third column of Table 3.

- **Centralized:** In this kind of architecture, the main component of the system is located on a centralized server. In other words, the major functions of the program run by a main centralized component. In case, all or most of the information is stored and processed on a centralized server, any failure of it will cause the whole system to fail. For this type of architecture, services are usually provided by centralized road-side server, while vehicles are regarded as clients.

  Among the studied projects, Road-Accident, Gas-Station, and TCE systems have centralized architecture. In Road-Accident system, services are provided by the centralized monitoring center, which notifies the final users (police station, ambulance, fire station) upon the reception of messages from the crashed vehicles. Gas-Station system stores the gas station and price information on a centralized server. TCE system performs traffic reasoning on a centralized server.

- **Flat-distributed:** In a distributed system, the components are located on the network and communicate and coordinate their actions by message passing [62]. In flat-distributed architecture, the main component of the system is distributed in a flat structure on a set of nodes such that no central server is needed. In case of failure of one node, the system continues running. These kinds of systems are fault tolerant ones.

  Among the studied projects, CADAS, DBD, CAGFP, Electric-Vehicle, Overtaking, IDB, CFMS, InCarMusic, and CAPM systems have flat-distributed architecture. In CADAS, DBD, CAGFP, Overtaking, Electric-Vehicle and IDB systems, the application is provided by the vehicle onboard unit, where the vehicles communicate with each other via V2V communication. In fact, in these systems, the application is distributed on different vehicles, and each of them continues to run independently. CFMS, InCarMusic, and CAPM systems are based on web and Internet services. Since the Internet is a distributed network, these applications are also considered as distributed. The CAPM application is provided by smart servers that are located in the cloud.

- **Hierarchical-distributed:** In this architecture, the main component of the system is distributed in a hierarchical structure on a number of servers. On-Street-Parking and IR-CAS ACN systems have a hierarchical-distributed architecture. On-Street-Parking is based on a three-tier architecture where the first tier includes the OBU of vehicles. The second tier includes InfoStations each of which covers a certain parking zone. The service is provided by the InfoStations installed on the side of the street, which receive the parking request message from vehicles. The third tier consists of an InfoStation Center (ISC) that monitors and coordinates all InfoStations. IR-CAS CAN has a two-layer architecture. The first layer involves vehicles in which accident severity is computed. The second layer consists of the RSU, which is responsible for notifying emergence response centers as well as family of the driver.

- **Stand-alone:** These applications consist of only one component that runs on a single computer system (i.e. vehicle OBU), and have no communication with other computer systems. Among the projects, TOCADAS, CAISA, and CATE have one component that runs individually on each vehicle's onboard unit.

### 6-3 Communication Type

In general, there are two types of vehicular communication: V2V and V2I. Moreover, a stand-alone application does not require any communication. In below, the projects are investigated from the perspective of communication. Finally, the results are summarized in column 4 of Table 3.

- **Vehicle-to-Vehicle Communication (V2V):** Vehicles can be in direct communication with each other. This type of communication allows exchange and sharing of information between moving vehicles irrespective of road-side infrastructure. However, V2V communication has a limited range.

  The majority of the studied projects including CADAS, DBD, CAGFP, Overtaking, Electric-Vehicle, Gas-Station, IDB, and IR-CAS ACN systems use V2V communication in order to share information. The IDB and CADAS systems build on V2V communication for performing intersection coordination in order to decide who should go first. DBD system uses this type of communication to send corrective actions to other vehicles. CAGFP and IR-CAS ACN systems send notification packets of the accident to other vehicles via V2V communication. In Gas-Station system, the current prices of gas stations are shared among vehicles through V2V communication. Also Electric-Vehicle application shares real-time traffic data using V2Vcommunication.

On-Street-Parking and Road-Accident applications also build on this type of communication to extend the vehicular network communication range. In fact, these applications use V2V communication in order to exchange information between vehicles and road-side units whenever they are out of the transmission range of each other. In this situation, other vehicles act as intermediate nodes; they receive information and forward it in order to be in access of the road-side unit.

- **Vehicle-to-Infrastructure Communication (V2I):** V2I allows for wireless information exchange between vehicles and the infrastructure (e.g. road-side units). Because OBU of vehicles has limited computational and storage capabilities, some applications rely on the road-side servers as the middleware or platform. Among the studied projects, On-Street-Parking, Road-Accident, Gas-Station, CFMS, TCE, CAPM, and IR-CAS ACN applications use V2I communication. Sometimes V2I communication is utilized to access to the global urban information. For example, in Gas-Station system, the application makes use of V2I communication to use the information about gas stations. Similarly, TCE application extracts weather data and traffic congestion via V2I communication.

- **Stand-alone:** Applications in this category consist of only one component, which is resided on the vehicle OBU. Therefore, they have no communication with components outside the vehicle. From among the reviewed studies, TOCADAS, CAISA, InCarMusic, and CATE systems are in this category. In these applications, all required context is gathered by various sensors within the vehicle, and there is no need to gather contextual information from other vehicles or road-side servers.

**6-4 Application Action Pattern**

In general, action pattern of the context-aware applications in the vehicular network could be categorized into three groups: user initiated, periodic & background, and event-based. In the following, we survey the projects from the viewpoint of action pattern. Finally, the results are summarized in the 5$^{th}$ column of table 3.

- **User Initiated:** These applications act upon the user’s request and finish after providing service. Most of Convenience and Entertainment as well as traffic management applications perform action after direct request of the user. On-Street-Parking, Electric-Vehicle, InCarMusic, and CAPM systems are among these applications. Afterward, they provide the service and finish the execution.

- **Periodic & Background:** These applications run semi-automatically from the start of the movement of the vehicle until it stops. They include two types: (a) those that always act in the background and give services, and (b) those that do actions periodically. IDB, CAISA, and CATE applications are of this category. In IDB system, cameras and sensors always monitor the surrounding environment and alarm the driver in hazardous situations. In CAISA system, speed control is performed periodically. The system receives the location and speed information from GPS every 10 seconds, and regulates speed by obtaining the speed limit. It is performed through interpolating the speed limit on the digital map, and comparing the speed of the vehicle and speed limit of the segment. In CATE system, the local traffic congestion is estimated periodically. In this system, every vehicle records its instantaneous speed at 1 second constant intervals. Therefore, it computes the average speed and mean absolute acceleration (MAA) using the recorded instantaneous speeds of the last 5 seconds period. Then, the vehicle measures traffic congestion level using this contextual information.

- **Event-based:** These applications are automatically triggered and act, whenever a particular event occurs such as, when the speed exceeds the speed limit or the risk of collision is detected. Most of the safety applications perform action upon the occurrence of a certain event. In fact, safety applications always monitor the vehicle state and surrounding environment; when a risk of collision is detected, they perform action (e.g. sending an alarm).

**Table 3: Survey results: system-and-application dimension**

| Project Name | Service Type | System Architecture | Communication Type | Action pattern |
|---|---|---|---|---|
| **On-Street-Parking [40]** | Convenience & Entertainment | Hierarchical-distributed | V2V , V2I | User Initiated |
| **TOCADAS [41]** | Safety | Stand-alone | Stand-alone | Event-based |
| **CADAS [42, 43]** | Safety | Flat-distributed | V2V | Event-based |
| **Road-Accident [45]** | Safety | Centralized | V2V , V2I | Event-based |
| **DBD [46]** | Safety | Flat-distributed | V2V | Event-based |
| **CAGFP [47]** | Safety | Flat-distributed | V2V | Event-based |
| **Electric-Vehicle [48]** | Traffic Management | Flat-distributed | V2V | User Initiated |
| **Overtaking [49, 50]** | Safety | Flat-distributed | V2V | Event-based |
| **Gas-Station [51]** | Convenience & Entertainment | Centralized | V2V , V2I | Event-based |
| **IDB [52]** | Safety | Flat-distributed | V2V | Periodic & Background |
| **CAISA [53]** | Safety | Stand-alone | Stand-alone | Periodic & Background, Event-based |
| **CFMS [54]** | Convenience & Entertainment | Flat-distributed | V2I | Event-based |
| **InCarMusic [55]** | Convenience & Entertainment | Flat-distributed | Stand-alone | User Initiated |
| **TCE [56]** | Traffic Management | Centralized | V2I | Unknown |
| **CAPM [57]** | Convenience & Entertainment | Flat-distributed | V2I | User Initiated |
| **CATE [59]** | Traffic Management | Stand-alone | Stand-alone | Periodic & Background |
| **IR-CAS ACN [60]** | Safety | Hierarchical-distributed | V2V , V2I | Event-based |

Among the reviewed applications, TOCADAS and CADAS systems act upon detecting the risk of collision. Similarly, Road-Accident, CAGFP, and IR-CAS ACN systems perform action after detecting an accident. DBD system starts action once it detects the abnormal behavior of the driver. In Overtaking system, when the driver's intent to overtake is perceived, the driving scene is analyzed and the reasoning process gets initiated. In CAISA system, the vehicle's acceleration is controlled as the gears are switched. When the driver switches gears, the current revolution of the engine is compared with the engine's max revolution, and regulated as required.

Similarly, Gas-Station system initiates to act when the fuel level of the vehicle has considerably decreased by indicating the available cheap gas stations. Finally, CFMS system acts whenever the user reports breakdown or an accident to the central server.

## 7- Prominent Projects Review: Context-Awareness

Since context-awareness is an important aspect of the VANET applications, we devote the third dimension to it. This dimension includes the parameters of "context type" and "context gathering method", as follows:

### 7-1 Context Type

Context-aware applications in vehicular network are based on contextual information. In other words, each application relies on particular context types. Before investigating the required contextual information of the projects, we generally categorize context in transportation domain into four groups including "local", "external", "general-related to transportation", and "general-unrelated to transportation". Afterward, we review the required context elements of the projects according to the categorization.

- **Local Context:** This type of context information describes a local entity, i.e., the driver or his vehicle. Such context information as the location, speed, and acceleration of the vehicle, and the driver's age and gender are considered as local contextual information.

  All of applications use local context information except for TCE system. Some of the local context including speed, acceleration, location, direction, and distance to neighboring vehicles or objects are used by most of the applications. For instance, the vehicle's speed and acceleration are used by TOCADAS, Road-Accident, DBD, Electric-Vehicle, CAGFP, Overtaking, CADAS, IDB, CAISA, and CATE. Similarly, the location of the vehicle is utilized by On-Street-Parking, Road-Accident, DBD, CAGFP, Gas-Station, IDB, CAPM, CFMS, and CAISA.

  Other local context including type and size of the vehicle, mass and frontal area of the vehicle, the vehicle's number, behavior and sleepiness of the driver, and type and level of the vehicle's fuel are rarely used. For example, the context information of type and size of the vehicle is used by On-Street-Parking system, the mass and frontal area of the vehicle is used in Electric-Vehicle system, the type of fuel, the level of fuel and amount of fuel consumption are used by Gas-Station system.

- **External Context:** This context describes other vehicles or drivers (external nodes) such as the location, speed and acceleration of other vehicles or information about other drivers.

  From among the studied projects, only a few of them utilized external context; they include CADAS, DBD, CAGFP, Overtaking, and CFMS systems. As elaborated in Table 4, the context information of speed, acceleration, distance, location, and direction of other vehicles are generally used in these applications.

- **General-Related to Transportation:** General context relevant to transportation lie in this category such as traffic and parking information. In other words, this category involves contextual information that are related to the transportation, but do not describe vehicles and drivers.

  This kind of context is used by many systems including On-Street-Parking, Road-Accident, DBD, Gas-Station, Electric-Vehicle, CFMS, Overtaking, CADAS, IDB, TCE, CAPM, and CATE. For example, On-Street-Parking application uses a set of general context relevant to transportation such as size and location of the available parking spaces, parking policies, parking prices, and serial number and location of InfoStations to locate and reserve parking. CADAS application uses the color of traffic signs to recognize traffic signs and notify the driver of the signs. Electric-Vehicle system builds on general context concerning traffic level, speed limit, slope angle and road length, travel time, and road energy cost to calculate the optimal route. Also, in Gas-Station system, fuel price, name and location of the gas station, and available fuel types of gas stations are used.

- **General-Unrelated to Transportation:** Other general context that is not relevant to transportation is put under this category such as weather condition.

  These pieces of information are used by a few applications. Among the studied projects, TOCADAS, Road-Accident, DBD, Electric-Vehicle, CFMS, InCarMusic, and TCE systems use this kind of context. For example, Road-Accident application uses the number of people died and injured, and presence of fire and lethal gas to notify emergency forces. Besides, workday, day of the week, time of the day, school break, and weather data are used in TCE application to estimate the traffic state of the road segment.

**Table 4: Context information used by context-aware vehicular applications**

| Project Name | Context Type | | | |
|---|---|---|---|---|
| | Local Context | External Context | General-Related to Transportation | General-Unrelated to Transportation |
| On-Street-Parking [40] | Driver profile, vehicle profile, vehicle location, gap space between vehicle and adjacent vehicles in parking space, driver parking preferences, driver parking destination and duration | | Size and location of the available parking spaces, parking policies, parking prices, serial number and location of InfoStations | |
| TOCADAS [41] | Vehicle speed, acceleration, longitudinal distance between the vehicle and neighboring vehicles, lateral distance between the vehicle and neighboring vehicles | | | Humidity, friction, visibility |
| CADAS [42, 43] | Vehicle drift on the road, distance between the vehicle and other objects or vehicles, speed and arrival time of vehicle to the intersection, distance of vehicle to the intersection ahead | Speed and arrival time of other vehicles to the intersection, distance of other vehicles to the intersection | Color of traffic signs | |
| Road-Accident [45] | Vehicle retardation, vehicle tilt, force imparted in the vehicle, accident type, vehicle number, accident location, accident's sound | | Number of vehicles imparted in the collision | Number of people died and injured, presence of fire and lethal gas |
| DBD [46] | Vehicle speed, acceleration, vehicle position between lane markers, state of the driver's eyes, alcohol level in the driver's blood, driver behavior, position and direction of vehicle | Speed, position and direction of other vehicles | | Time and time zone, noise, temperature |
| CAGFP [47] | Speed, acceleration, position and direction of vehicle | Speed, acceleration, positions and direction of neighbor vehicles, surrounding topology (list of neighbors vehicles) | | |
| Electric-Vehicle [48] | Vehicle friction coefficient, vehicle mass, vehicle speed and acceleration, frontal area of the vehicle, kinetic and gravitational potential energy of the vehicle, energy conversion efficiency of the vehicle, vehicle battery charge, vehicle battery capacity, origin and destination of the vehicle, departure time | | Traffic level, road speed limit, road slope angle, road length, road travel time, road energy cost | Gravity acceleration, air density, air resistance coefficient |
| Overtaking [49, 50] | Current speed of vehicle, overtaking speed of vehicle, vehicle length, vehicle width, distance between front and own vehicle, distance between vehicle and oncoming vehicle, distance between vehicle and approaching vehicle, distance between vehicle and the vehicle in the overtaking lane, vehicle's current line of sight, vehicle's stopping distance, side distance between vehicle and overtaken vehicle, driver state | Length of the front vehicle, speed of the front vehicle, speed of the oncoming vehicle, speed of the approaching vehicle, speed of the vehicle in the overtaking lane, available space on the left in the lane of the overtaken vehicle | Lane width, road surface conditions | |
| Gas-Station [51] | Vehicle position, vehicle direction, vehicle route, fuel type of the vehicle, fuel level of the vehicle, vehicle fuel consumption, user preferences | | Fuel price, gas stations location, gas stations name, available fuel types of gas stations | |
| IDB [52] | Vehicle speed, vehicle position, distance of vehicle to other objects or vehicles | | Road traffic signs | |
| CAISA [53] | Vehicle speed, vehicle acceleration or engine revolution, vehicle position, amount of driven kilometers | | | |
| CFMS [54] | Vehicle location, accident report of the vehicle(crash/breakdown), vehicle departure time, vehicle arrival time, storage condition of the goods(temperature and humidity), vehicle information(vehicle ID, capacity, available time frame), driver information(driver ID, driver name, available time frame) | Location of other fleet vehicles | Trip information (shipping/service items, starting point, ending point, time window, priority) | Customer information(customer name, contact person, priority) |
| InCarMusic [55] | Driving style(relaxed driving, sport driving), sleepiness(awake, sleepy), mood(active, happy, lazy, sad) | | Road type(city, highway, serpentine), traffic conditions | Landscape(coast line, country side, mountains/hills, urban), weather, natural phenomena(day time, morning, night, afternoon) |
| TCE [56] | | | Traffic congestion, mobile phones data of road segment, estimated traffic congestion | Work-Day, day of the week, time of the day, school break, weather |
| CAPM [57] | Vehicle location, vehicle destination, user information | | Parking state(available, reserved, in use, load/unload), traffic state | |
| CATE [59] | Average speed, mean absolute acceleration | | local traffic congestion level | |
| IR-CAS ACN [60] | Accident severity, driver personal information, accident indicators(vibration, noise, pressure, temperature, Delta V), injury indicators(belt_use, multiple impacts, rollover, make, occupants, model) | | | |

### 7-2 Context Gathering Method

The projects utilize diverse methods to gather their required contextual information. In general, each context is gathered through one of the methods of sensor/onboard devices, cloud and internet service, static infrastructure, user interface, or an inference component, as follows:

- **Sensor/On-board devices:** A majority of vehicular context information is directly sensed by different types of sensors and on-board devices in the vehicle as well as any other devices carried within the vehicle like the driver's mobile phone. The vehicular applications mostly rely on this mechanism to gather the required context elements. In fact, the vehicle's local and external context is usually gathered by on-board devices and sensors.

  Column 2 of table 5 summarizes the contextual information that is gathered by this mechanism.. All of considered studies except for InCarMusic system utilize on-board devices and sensors to gather a great part of the required context information. Part of this context information such as the vehicle's length, width, and mass is statically available on the vehicle's database. For instance, the vehicle's profile and the driver's profile are gathered from the data repository of the vehicle in On-Street-Parking system. In Electric-Vehicle system, the speed limit and length of any road link is obtained from the stored map on the vehicle. Similarly, in the Overtaking system, the current line of sight of the vehicle is obtained from the knowledge base of the vehicle. Some other context elements including the location, speed, acceleration, distance and direction of the vehicle are gathered by the vehicle's sensors.

- **Cloud and Internet Services:** Internet, cloud, and web services are sometimes utilized as context sources. From among the projects, it is only TCE and CAPM systems that use this mechanism. In TCE application, the context information of rain is extracted from the weather log, traffic congestion degree from the traffic log, and workday, day of the week, time of the day, and school break from "time log", which are provided as web services. In CAPM application, the traffic state of urban areas is received from smart servers that are based on cloud processing.

- **Static Infrastructure:** Static road-side infrastructure could be utilized as a source for driving contextual information. Among the projects, On-Street-Parking and Gas-Station have used road-side infrastructure to gather context information. In On-Street-Parking system, the parking policies and prices are provided by the InfoStations data repository installed on the side of the street, and serial number and location of each InfoStation is acquired by the InfoStation Center (ISC) data repository. In Gas-Station system, fuel price, name and location of the gas stations and available fuel types of gas stations are provided by a central server.

- **User Interface:** Some of the context elements are entered by the users through the graphic interfaces. On-Street-Parking, Road-Accident, Electric-Vehicle, Gas-Station, CFMS, InCarMusic, and CAPM applications make use of this mechanism. For example, in On-Street-Parking application, the driver's parking preferences, and parking destination and duration, are entered by the user through the interface. In Road-Accident system, the number of vehicles imparted in the collision, the number of people died or injured, and the presence of fire and lethal gases are provided by people around the crashed vehicle(s) through the interface of their smartphones. In CFMS application, the information concerning the vehicle, the driver, and the customer(s) is entered by the system's designer through the interface. In addition, the accident report is sent to the central server by the driver through the interface of this system.

- **Inference Component:** In this mechanism, context is obtained from an inference software component. Some of the high-level context types like the traffic state and the driver's behavior cannot be obtained solely by one sensor. High-level context elements are usually inferred from aggregation of several pieces of low-level contextual information.

  From among the studied applications, On-Street-Parking, DBD, Road-Accident, CAGFP, Electric-Vehicle, TCE, CATE, and IR-CAS ACN exploit this mechanism for context gathering. In On-Street-Parking system, the sensors installed on the vehicle sense information about the surrounding objects and obstacles, and then send them to the road-side servers. The size and location of vacant parking spaces are inferred from aggregating these pieces of information gathered from different vehicles. In Road-Accident application, the type of vehicle accident such as rear-end collision, head-on collision, and side collision is inferred using three types of contextual information including sudden retardation of the vehicle, tilt of the vehicle, and force imparted in the vehicle by DMU (decision making unit) located in the on-board system of the vehicle.

  DBD system reasons the driver's behavior by aggregating the contextual information related to the driver, the vehicle's state, and changes in the environment. In CAGFP system, each vehicle periodically receives beacon messages containing position, direction, speed, and acceleration of other vehicles within its transmission range, and reasons its surrounding topology from the aggregation of these pieces of information. In Electric-Vehicle system, the traffic level of a road is reasoned by any vehicle as the ratio of the average speed of the vehicle to the speed limit of the road. In TCE system, congestion index of a road segment is reasoned from the aggregation of a set of historical and current contextual information including workday, day of the week, time of the day, school break, weather data, traffic congestion degree of road segment, and mobile phones data regarding the road segment. In CATE system, local traffic congestion level is inferred using the average speed and mean absolute acceleration (MAA) of the vehicle based on a fuzzy logic approach. Finally, IR-CAS CAN inferences accident severity from contextual information related to driver and vehicle.

**Table 5: Context gathering mechanisms in context-aware applications of vehicular network**

| | **Context Gathering Method** |
|---|---|

| Project Name | Sensor/On-board devices | Cloud & Internet Services | Static Infrastructure | User Interface | Inference Component |
|---|---|---|---|---|---|
| **On-Street-Parking [40]** | Driver profile, vehicle profile, vehicle location, gap space between vehicle and adjacent vehicles in parking space | | Parking policies, parking prices , serial number and location of InfoStations | Driver parking preferences, driver parking destination and duration | Size and location of the available parking spaces |
| **TOCADAS [41]** | Vehicle speed, acceleration, longitudinal distance between neighboring vehicles, lateral distance between neighboring vehicles, humidity, friction, visibility | | | | |
| **CADAS [42, 43]** | Vehicle drift on the road, distance between the vehicle and other objects or vehicles, speed and arrival time of vehicle to the intersection, speed and arrival time of other vehicles to the intersection, distance of vehicle to the intersection, distance of others vehicles to the intersection, color of traffic signs | | | | |
| **Road-Accident [45]** | Vehicle retardation, vehicle tilt, force imparted in the vehicle, vehicle number, accident location, accident's sound | | | Number of vehicles imparted in the collision, number of people died and injured, presence of fire and lethal gas | Vehicle accident type |
| **DBD [46]** | Vehicle speed, acceleration, vehicle position between lane markers, state of the driver's eyes, alcohol level in the driver's blood, position and direction of vehicle, time and time zone, noise, temperature, speed of other vehicles, position and direction of other vehicles | | | | Driver behavior |
| **CAGFP [47]** | Speed, acceleration, position and direction of vehicle, speed, acceleration, positions and direction of neighbor vehicles | | | | Surrounding topology |
| **Electric-Vehicle [48]** | Vehicle friction coefficient, vehicle mass, vehicle speed and acceleration, frontal area, kinetic and gravitational potential energy of the vehicle, energy conversion efficiency of the vehicle, vehicle battery charge, vehicle battery capacity, road speed limit, road slope angle, road length, road travel time, road energy cost, gravity acceleration, air density, air resistance coefficient | | | Origin and destination of the vehicle, departure time | Traffic level |
| **Overtaking [49, 50]** | Current speed of vehicle, overtaking speed of vehicle, vehicle length, vehicle width, initial distance between front and own vehicle, second safety distance of vehicle for realignment after overtaking, distance between vehicle and oncoming vehicle, distance between vehicle and approaching vehicle, distance between vehicle and the vehicle in the overtaking lane, vehicle's current line of sight, vehicle's stopping distance, side distance between vehicle and overtaken vehicle, length of the front vehicle, speed of the front vehicle, speed of the oncoming vehicle, speed of the approaching vehicle, speed of the vehicle in the overtaking lane, lane width, road surface conditions | | | | |
| **Gas-Station [51]** | Vehicle position, vehicle direction, vehicle route, fuel type of the vehicle, fuel level of the vehicle, vehicle fuel consumption | | Fuel price, gas station location, gas station name, available fuel types of gas stations | User preferences | |
| **IDB [52]** | Vehicle speed, vehicle position, distance of vehicle to other objects or vehicles | | | | |
| **CAISA [53]** | Vehicle speed, vehicle acceleration, vehicle position, amount of driven kilometers | | | | |
| **CFMS [54]** | Vehicle location, , vehicle departure time, vehicle arrival time, storage condition of the good, location of other fleet vehicles | | | vehicle information, driver information**,** customer information**,** trip information | |
| **InCarMusic [55]** | | | | Driving style, sleepiness, mood, road type, traffic conditions, Landscape, weather, natural phenomena | |
| **TCE [56]** | Mobile phones data of road segment | Work-Day, day of the week, time of the day, school break, weather, traffic congestion | | | Estimated traffic congestion |
| **CAPM [57]** | Vehicle location, parking state (available, reserved, in use, load/unload) | Traffic state | | Vehicle destination, user information | |
| **CATE [59]** | Average speed, mean absolute acceleration | | | | traffic congestion |
| **IR-CAS ACN [60]** | Driver personal information, accident indicators, injury indicators | | | | Accident and injury severity |

## 8- Conclusion and future research directions

Context-aware vehicular network has provided opportunities for improving intelligent transportation systems by supporting inter-vehicle as well as vehicle to road-side communications. It has provided a wide range of transportation applications, which are aware of the driving environment. In this survey, context-aware applications of the vehicular network have been reviewed from the three dimensions of environment, system and application, and context-awareness. One or more parameters have been introduced for each dimension, and the applications have been analyzed accordingly. In general, these applications have been classified into three main categories involving safety, traffic management, and convenience and entertainment. Other classifications have also been made according to other parameters.

Although there have been traditional research in some of the application areas, context awareness improves the services to a higher level. For example, a typical none-context-aware service for safety[63] makes use of image processing and eye tracking to detect driver drowsiness. Therefore, the driver's face should always be opposite the camera and any change in the position, could stop the system from functioning. In addition, the level of illumination could negatively influence the system. However, in addition to image processing, a similar context-aware application [46] makes use of sensors and contextual information such as driver state (By alcohol sensor), car context (velocity, acceleration, etc.), and noise of the environment to detect behavior of the driver. A context-aware approach could detect the drunkenness of a driver by comparing the acceleration by the behavior pattern of the driver and inform nearby drivers and police station upon recognizing a drunk driver. Alternatively, the context-aware system could recognize the drunkenness of the driver by detecting zigzag pattern of drive or periodic lane changes. The utilization of various sensor types facilitates to detect the situation more pervasively and dynamically and to provide higher level services. As another example, in traffic management service, traditional approaches usually exploit loop detectors [64, 65] or cameras [66, 67] for traffic estimation. This results to several drawbacks: They could only estimate traffic in the deployed places. They usually generalize traffic of a point to the entire street. Moreover, they impose much cost for deployment and maintenance. On the other hand, context-aware approaches[59] are based on the information generated by numerous wearable and mobile sensors available in the cars. They provide accurate traffic information more dynamically and ubiquitously.

The results indicate that few studies have been conducted on various application types in this area and there is a potential to investigate on these areas. Besides, many projects are in the design phase which shows that the infrastructure is not yet fully provided. This involves close collaboration between automobile industry and academia. In general, the field of context-aware vehicular network applications is a new and growing area, which expects good perspective for the future. There are still different research challenges as follows:

- Diverse scenarios can be proposed for addressing different issues such as collision avoidance at the time of overtaking in rural roads (which are usually bi-directional), global traffic measurement and sharing, and traffic management in intersections without traffic lights, among others. However, designing and deploying a context-aware system requires context gathering, processing, and reaction, which is regarded as a challenging issue.

- Smart transportation systems usually need high-level contextual information like traffic state and driver's behavior. Real-time access to this information, which changes dynamically, is a vital issue. This requires identification of effective context information and deriving an appropriate model for instantly reasoning this high-level context. Besides, the emerging area of mobile crowd-sensing could be investigated to globally obtain a high-level context such as traffic level or urban parking vacancies.  In this model, each vehicle is regarded as the mobile device, which could senses various local information. The backend server could leverage of the cloud platform to aggregate and process the obtained information from vehicles.

- Modern vehicles are equipped with computation and communication capabilities that can sense local information about road condition, speed, acceleration and position of the vehicle, among others. This huge volume of information that is gathered from different vehicles should be managed and aggregated in order to reduce the memory and bandwidth consumption. Management of this volume of dynamic information includes several processes including gathering, aggregation, validation and dissemination of information on the VANET. It is a fundamental challenge that requires the design and development of middleware that involves smart routing protocols for establishing effective communication and improving information dissemination between vehicles.

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