Exploiting IoT and Big-Data for Building Multi-service Capable Intelligent Transportation Systems

Theofanis Orphanoudakis, Anastasios Fanariotis, Ilias Politis and Theodoros Karachalios
School of Science and Technology
Hellenic Open University
Tsamadou 13-15, GR-26222, Patras, Greece
{fanis, afanariotis, ilpolitis}@eap.gr

Konstantinos Demestichas, Stavros Xynogalas, Ioannis Loumiotis and Efstathios Sykas
Computer Networks Laboratory
Institute of Communication and Computer Systems (ICCS)
Iroon. Polytechniou 9, 157 73, Zografou, Greece
{cdemest, stavrosx, i_loumiotis, sykas}@cn.ntua.gr

Abstract— **All vehicles manufactured during the last decade are equipped with a variety of sensory instruments, providing their collected data through processing units (On Board Units) and customized interfaces (such as OBD-II). This makes a wealth of information available to different players making use of next generation Intelligent Transportation Systems (ITS). Such players obviously include the drivers but not alone, since the entire ecosystem includes fleet management services, highway traffic management systems, car manufacturers, public transportation systems and services etc. Combining the above sensor network technologies with technologies for connected cars and cloud computing applications a wide range of location-based services can be developed bringing a higher level of intelligence to next-generation transportation systems. In this paper we present the approach of the MANTIS project towards the above objectives. MANTIS aims at designing a comprehensive framework for the development of heterogeneous applications in intelligent transportation systems and at implementing and demonstrating driver assistance systems towards improvement of road transport. The MANTIS framework will exploit technologies of rapidly growing sensor and vehicular networks and will pursue their integration with Internet technologies and cloud applications.**

I. INTRODUCTION

During the last two decades, several technical groups such as the IEEE 1609 Working Group, the IEEE 802.11p Task Group, the ISO TC204 Working Group 16 and the ETSI ITS Technical Committee, work towards developing technologies and standards for the implementation of Vehicular Ad Hoc Networks (VANETs) [1]. In the context of these evolving standards, three main categories of applications are targeted: (i) road safety, (ii) traffic efficiency, and (iii) value added applications. Additionally, the advent of Release 14 of Long Term Evolution (LTE) and evolving 5G network standards promise to enable vehicular communications providing super-fast, reliable, and low latency connections [2]. Thus, all vehicles are expected to exploit Internet access and new services can be conceived on top of this infrastructure delivering on the promise of connected vehicles.

While the enhanced network infrastructure deployment is already underway, applications that can exploit these enhancements need to be developed. Such applications need in turn to exploit the advances in highly efficient sensor networks and embedded systems and the variety of in-car sensory instruments that provide their collected data through on-board processing units (OBUs) or even wearable sensors carried by vehicle passengers. Finally, appropriate protocols and networking services must be employed in order to provide the necessary communication channels and data aggregation and processing in an efficient and distributed architecture.

In the above context the MANTIS (Multiservice cApable iNtelligent TransportatIon Systems) project consortium members are collaborating towards developing a solution that will exploit technologies of rapidly growing sensor and vehicular networks and will pursue their integration with Internet technologies and cloud applications [3]. The MANTIS consortium comprises the Greek office of the traffic technology group SWARCO, the Attica Tollway motorway operation company Attikes Diadromes S.A., the Institute of Communication and Computer Systems (ICCS) of the School of Electrical and Computer Engineering (ECE) of the National Technical University of Athens (NTUA) and the Digital Systems and Media Computing Laboratory (DSMC Lab) of the School of Sciences and Technology of the Hellenic Open University (HOU). MANTIS aims at developing the architecture and technological solutions focusing on applications that will:

- enable geolocation of vehicles via the application of various methods for the reliable and continuous position detection, regardless of environmental and network conditions
- enable the collection and dispatch of useful data for recording primary vehicle operational parameters, cargo and passenger status, through appropriate Internet interfaces and protocols
- enable the automatic execution of emergency calls via Internet communications (VoIP) - even in cases of passengers' incapacity - by means of automatic call routing, to the appropriate/closest management and driver assistance centers, based on vehicle's location, accompanied with critical data from the on-board sensory instruments (NG-eCall)
- enable the collection and transmission of useful data for tracking environmental and extraordinary conditions by external infrastructure management centers (e.g. road operators, prefectures etc.) as well as by fleet management systems for corporate (M2M) applications,

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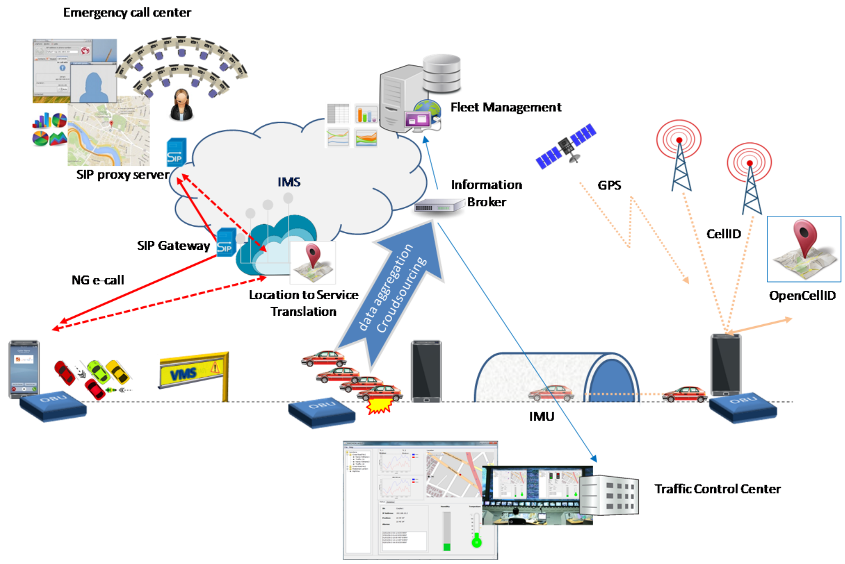

Fig 1 The MANTIS ecosystem and applications.

exploiting crowdsourcing techniques and intelligent big data analytics

- enable interoperability and customized (or based on geographic criteria or current conditions) connection and dispatch of data to the selected management and control centers as well as access to third party services.

The overall MANTIS ecosystem where the above applications and services are deployed is graphically shown in Fig. 1.

The rest of the paper is organized as follows. In section II, we review the related work in the fields of interest. The proposed MANTIS framework architecture is presented in section III. In Section IV, V and VI, the details of the MANTIS technological components are presented and discussed respectively, while in Section VII we describe the implementation details of the first prototype that is currently under development. Finally, Section VIII concludes the whole paper.

II. Related Work

The work of MANTIS is related to advances in the fields of vehicle positioning and state information gathering via IoT, emergency response in case of driver need and data analytics methods enabling added value services to drivers and players involved in the transportation business. We review below separately the progress in each of the above fields.

A. Geolocation Tracking

Positioning information is vital in transportation systems and the basis for developing and offering of services such as merchandise tracking, emergency call systems and effectiveness of transportation routing. While most of modern vehicles today are equipped with navigational systems integrated to its factory network the necessity for this kind of data dictates that location information should always be available for a vehicle even when it is not equipped with a geolocation navigational subsystem in order for any ITS to function effectively [4].

B. In-car IoT Networks

Nowadays the onboard controllers of modern cars are producing an extreme amount of data related not only to car engine and accessories functionality but to environmental and car subsystems states. Capturing a subset of this data is extremely useful in creating state models according to requirements. Such models can be enhanced with extra information from in-car sensors that complement the structure of these models and provide redundancy in case of a malfunction or an otherwise missing dataset.

The data produced from factory-installed car sensors are captured from the on-board controllers and transmitted over a factory installed in-car wired network with a well-specified protocol (such as CAN). The complete system is named OBD [5] and current version is defined as OBD II. Such data may include measurements ranging from vehicle fuel rate consumption to road friction and vehicle stability data; thus, the basis for constructing a multi-purpose state capturing system are already present on the vehicle's factory data network [6].

All this data may be supplemented by data captured from in-car sensor arrays in the form of driver or passengers wearable sensing devices or smart environmental and human state aware systems (e.g. Driver eye position/movement tracking or heart rate sensing from activity watches) providing a full dataset that in turn may be used to construct a full human and vehicle state model [6].

This state model may be constructed using well-known and well-defined methods [33] that may have been developed for other usage types, such as, smart-city applications but they do fit to in-car networks/sensing scenarios extremely well.

In order to capture all this useful information an in-car network is required centralized around a main device with a minimum requirement of network managing and data storage [7].

C. Next Generation e-Call (NG e-call)

The first generation eCall was a European initiative intended to bring rapid assistance to motorists involved in a collision anywhere in the European Union and was designed for circuit switched networks based on the GSM mobile technology. More recently, IP-based emergency services are turning to use broadband IP infrastructures, although emergency systems still need to adapt to fulfil regulatory and interoperability requirements. Thus, during the last few years several research projects have studied the integration of IP to emergency systems in Europe [9], [10], [11] and worldwide [12]. According to the definition of this architecture, emergency calls are delivered through the Emergency Services IP network (ESInet), which is designed as an IP-based inter-network, handling IP communications based on the Session Initiation Protocol (SIP) [13] and providing the required functionality to appropriately process and route sessions based on location information.

Latest efforts focusing on providing emergency services' to users over IP-based communication technologies include the NEXES NEXt generation Emergency Services and EMYNOS – nExt generation eMergencY commuNicatiOnS EU funded projects [9], [10]. NEXES aimed at supporting a total conversation service to citizens in general and persons experiencing impairments. NEXES proposed the integration of the sensor devices using the MSD format in order to establish automatically SIP-based emergency calls. EMYNOS was an EU founded project running in parallel to NEXES proposing a next generation emergency management platform capable of accommodating rich-media emergency calls that combine voice, text, and video. Finally, another complementary European initiative is the Infrastructure Harmonised eCall European Pilot I_HeERO project [11]. I_HeERO focuses on piloting the deployment of EU-wide eCall and interoperability of PSAPs (Public Safety Answering Point) in Member States for the deployment of eCall based on 112 as reference implementations.

While the above projects have only recently delivered the first prototypes for an infrastructure that can efficiently support next generation IP based emergency communication services including NG eCall, interoperable end user platforms that can efficiently exploit this infrastructure are still open to research. The above projects have demonstrated that rich-media IP based emergency communications, with efficient location-based service routing and sensor information encapsulation in different formats are feasible and identified the requirement for enhanced client platforms that can present the enhanced functionality to the end users using landline IP-phones, mobile smartphones or a connected car platform.

D. Big-data Analytics

The exploitation of big data in the field of ITS has been studied in many research papers. The majority of these works aim to improve the transportation systems by trying to accurately predict the forthcoming traffic flow. In this light, many methods have been proposed, such as the autoregressive integrated moving average (ARIMA) models [14] from 1970s, and their variants Kohonen-ARIMA (KARIMA) [15], subset ARIMA [16], seasonal ARIMA (SARIMA) [17] etc. Apart from that, many other attempts have been proposed to exploit the big data nature of the transportation systems, such as Bayesian approaches [18], Artificial neural network approaches [19]-[20] and deep learning approaches [21].

Other works in the literature that employ big data in the ITS sector include [22], in which the authors propose a novel system that uses sensors to control the traffic lights at intersections by employing genetic algorithms and fuzzy control methods and [23] in which the authors present the challenges of big data in social transportations.

The main objective of the above works is to a specific field, i.e. that of traffic flow, in a vast domain which is the ITS. In the current work, the proposed framework can be used on top of these works, exploiting their results and providing big data analytics services that can exceed a traffic flow task providing an overall solution in the ITS domain.

III. The MANTIS Architecture

Following the discussion in the previous sections about the MANTIS objectives and involved technologies we present below the technological components of the MANTIS framework architecture that will be developed to support the applications and services of interest.

As far as accurate and uninterrupted geolocation tracking is involved, MANTIS will exploit navigational systems inside the OBUs potentially combined with smart mobile devices that can easily provide location information with multiple methods (GNSS, mobile phone tracking, IMU data). Their combination also provides sufficient redundancy to make position information available under any circumstances, but also flexible application development to serve users. Additionally, OBUs retrieve valuable vehicle data and status information, which can be exploited by several location-aware transportation services. These modules are developed around different operating systems, such as Android, Linux, Windows Mobile, and can support e.g. reading vehicle speed, distance traveled, torque, fuel consumption, braking events and other parameters. Sensor networks either on-board (interconnected via the OBU), but also additional potentially wearable sensors (such as smart watches, health trackers, etc.) complete the aggregation gathering from the sources on interest inside moving vehicles.

The operation of data retrieval and interconnection to the Internet is achieved in the case of mobile vehicles via 3G/4G /5G-based mobile communications networks. The infrastructure of these networks also provides basic services relating to: additional location information for mobile devices (in addition to using GPS / GNSS satellite systems), address resolution and call routing services and, basic multimedia communications services.

Beyond the default backbone network nodes of the infrastructure, specific service and protocol extensions are needed to support new data formats and emergency call implementation specifications (NG-eCall) and data capture and representation protocols from in-vehicle sensors. These extensions are necessary to automatically make emergency calls via Voice over IP (VoIP) automatically by routing calls based on vehicle location data to the appropriate/closest to the vehicle/driver in need support centers and sending all critical data from on board sensors. In this case, communication is based on enhanced infrastructure servers for address resolution and emergency location routing.

In addition to the above-mentioned modules for multimedia communications that support emergency calls, the corresponding applications for call support and data management and representation should be developed. Thus, MSD (Minimum Set of Data) encapsulation formats as well as appropriate extensions e.g. to support SensorML, can be used to forward data to the control center and allow, in addition to the voice/video call, continuous streaming of data.

Given the communication platform described above for the automated NG eCall scenario, a set of applications can be used that can alternatively use sensor data. To exploit these data, the project will develop information aggregation and processing technologies through crowdsourcing for real-time intelligent analysis of large data streams and the accuracy of driving behavior and route assessments. This will be achieved by designing and installing a Big Data platform (including Data Warehouse, Analytics Unit and Information Broker) suitable for MANTIS purposes, implementing B2B and C2B interfaces for data collection, to be exploited by related applications and services. Thus, it is possible to detect environmental and traffic conditions of highways as well as in general applications that use the position data for the customized information of the passengers on vehicles for useful information about the location of the vehicle. In this way, all vehicles can be transformed into a distributed and extensive network of sensors that can be utilized by a traffic control center to detect environmental (e.g. wet or slippery road, frost, vehicle speed, etc.) and all kinds of conditions that can be recorded by the vehicles and transferred in real time to the control center. In the reverse direction, the control center can promote personalized driver information messages in geographically located areas, expanding the currently available information capabilities of Variable Message Signs (VMS). Finally, utilizing the bulk of data analysis, real-time guidance and real-time cloud evaluation services can developed along with route assessment services (safety, consumption, congestion) in real time. These services could be used to improve transport-related systems and services such as fleet management.

The components of the MANTIS framework architecture discussed above are shown in the architectural diagram in Fig. 2 below.

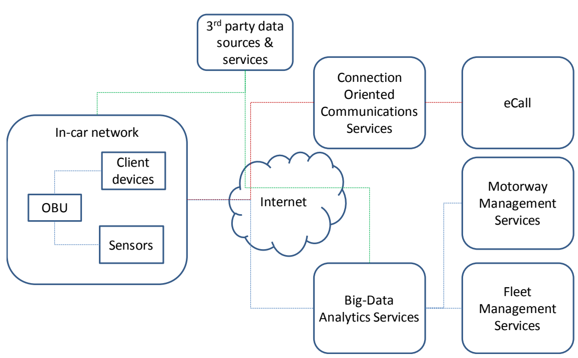

Fig 2 The MANTIS high-level architecture.

IV. In Car IoT Network

The proposed subsystem is by definition a heterogeneous networking and data collection system that interconnects the factory car OBD subsystems, any wearable devices that may be present on the vehicle's driver and any other peripheral sensing devices available in the passenger compartment. In order to easily connect multiple devices in a space constrained area with humans present without increasing their movement freedom or hinder driver's capability to operate the vehicle a wireless network must be used.

Among the available wireless networking technologies such as WiFi or Bluetooth [25], the latter prevails due to the low power requirements from wearable devices, the availability of Bluetooth capable OBD Reader devices and the factory fitted infotainment's native support for this type of connectivity.

The captured data are gathered on a central subsystem inside the vehicle. Such a device may serve as a network gateway as well as data storage or real time data preprocessor or processor, constructing real time models for direct usage in the vehicle. It may also include a singular interaction interface with the driver if such requirement exists either in the form of a visual display, audio notifications or remote GUI to smartphone server. This device will also provide access to services and connectivity to access networks available in the vehicle's location. Such a gateway can be materialized with the use of e.g. a Raspberry Pi like platform with Bluetooth and WiFi network interfaces for facilitating the in-car network.

For the purposes of this research, Sensor ML and MQTT protocols will be utilized for the formatting, encapsulation and transmission of the sensor data from the OBD and any other available sensor in the in-car area network. The required fusion, processing and management of the in-car network sensor data is taking place on the gateway.

V. Next-Generation E-Call

Within the concept of MANTIS a novel SIP based next generation eCall will be designed and validated for notifying of incidents across a highway. The aim of the new eCall extensions proposed in this research is to maximize the amount of data collected as part of the in-car network that can be transmitted any time an eCall is being triggered. The enhancement of existing eCall designs with multimodal sensor data, including OBD data, location, driver's conditions, cargo details, etc., along with real-time VoIP and video communication, in envisioned to greatly improve the overall PSAP's situation awareness, efficiently. The adaptation of SIP as the communication protocol eliminates the limitations of the current eCall system. The data is no longer transmitted in the voice channel prior to voice communication but in parallel. Furthermore, the available bandwidth is significantly higher. This enables the transmission of additional, optional data sets to be sent via the Minimum Set of Data (MSD), which in turn needs to be expanded.

The proposed next generation eCall may be considered an extension of a normal SIP emergency call. The initial SIP INVITE message contains all properties of a SIP emergency call, like using an emergency service URN (Universal Resource Name) as the address of the recipient of the call, sending a multi-part body that contains location information in the PIDF-LO/Next-Generation Pan-European eCall IETF format along with the SDP Offer. Extended eCalls should be easily identified to allow PSAPs to distinguish them from regular emergency calls and enable SIP routers to implement specific routing policies for extended eCalls. Consequently, the envisioned eCall will require the use of a specific SIP header field.

In today's eCall, data is sent via the audio channel by modulating the data as audio signals. In the SIP based eCall case, this is not necessary anymore, because the data can be transmitted directly. Depending of the type of data to be transmitted, three ways to transport the data are possible. Firstly, smaller amounts of data that are only sent once like the MSD can be included in the SIP INVITE message's body in the same manner as it is done for the location information. Secondly, it is also possible that small data sets like the MSD can be send in regular intervals included in the normal messages in the INFO session part. As third and last possibility, larger amounts of data or data that has to be transmitted continuously can be sent in a separate media stream whose description is included in the SDP Offer. If the receiving party does not support the enhanced eCall media stream, a regular audio emergency call can still be established.

Within the scope of MANTIS the proposed SIP-based eCall will be triggered by the in-car network gateway, which by acting as an OBD and other sensor data aggregator and processing function, decides upon alerting the MANTIS platform of an incident. Such incidents should include car crushes, abnormal driving behavior (i.e., sudden de-acceleration) or even driver's status conditions (i.e., driver fainting, etc.), based on the sensor device availability inside the car. Using both vehicle's and driver's condition data to initiate an e-call will provide the system with an accurate, albeit "sensitive" triggering method.

It is expected that this MANTIS subsystem will improve first aid and medical response times as other scientific studies and simulations have proved [32].

VI. Big-Data Analytics

Transportation systems are characterized by multiple roles, data streams and data correlations. The volume of the data, their velocity and their variety create the need to employ new approaches beyond the traditional data management systems. One of the most critical requirements for the big-data analytics system is the support of real time and near real time processing of big data, making all the data available to each stakeholder in an efficient way. During the last few years, many information flow models have been proposed along with ontologies that describe the drivers, the vehicles, the roads and the weather conditions [29]. Although these models are considered as the basis for ITS, MANTIS will go beyond them and exploit all the available data from heterogeneous sources that may seem unrelated and cannot fit in a traditional RDBMS system in order to provide real time data processing and road traffic analytics.

The Big Data platform as described above will collect data from heterogeneous sources both in real and non-real time for processing and extracting valuable information. The Big Data platform consists of three basic systems; the storage, the analyzer and the monitoring.

The storage system will be a Hadoop [30] database based on HDFS that will allow the storage of big data. For the database, several Hadoop clusters will be deployed. Hadoop clusters will assure the scalability of the system as more clusters will be easily deployed as the volume of data increase.

The analyzer will consist of a set of mappers and reducers, that will be used for processing the big volumes of data. The tasks that will be performed by the Big Data platform will be prescribed in the mappers, and then the reducers will be used to process the data from the mappers.

The monitoring system will be an event management system that will perform real time stream processing and will trigger appropriate actions when certain events happen. The monitoring system will continuously monitor the streams of data and will allow for real time actions that could not be performed by the batch processing of Hadoop. For the monitoring system, Apache Storm [31] will be used as it can offer high flexibility and a user-friendly deployment.

VII. Applications and Prototype Implementation

The prototype system that is currently designed acts as a proof of concept and data capturing device for the in-car IoT subsystem, which is the basis for delivering all MANTIS services and applications. Having the prototype integrated and tested will enable building the emergency response and ITS services around it, as well as provide valuable datasets from real-life road and vehicle conditions, when mounted on motorway patrol vehicles of Attikes Diadromes. Every design choice will be made towards the stability of the system but with the ability for easy extendibility to each design aspect in order to fully implement any future system upgrades.

Our current implementation is based on a Raspberry Pi 3 as a main gateway hardware platform running on Raspbian Linux. The device already supports Bluetooth V4.0 connectivity with LE capabilities and WiFi connectivity should such requirement arise. A group of external peripheral devices are integrated listed below.

- A sirf-star III based GPS module connected over USB supporting Assisted GPS mode for the basic geolocation data capturing.
- An MPU-9250 9DOF IMU/gyroscope module connected over I2C in order for acceleration events measurement as well as Inertial navigation model implementation
- A GPRS module in order to receive cellphone data for researching and implementing cell-towers triangulation location schemes
- A 3G/4G USB Modem/Transceiver in order to cover any system-to-cloud or system-to-server communication requirements
- An ELM327 Based Bluetooth OBD reader in order to capture data from the factory installed car data network in OBD2 Silent mode

Software wise, a data capturing application is under development that will have the following functionality:

- Capture serialized NMEA formatted geolocation data and parse it into usable geolocation (LON/LAT/ELEV) data

- Capture selected OBD2 PIDs data from vehicles network parse and store it in a human readable format
- Capture extreme acceleration events and raise internal or external exceptions
- Continuously capture acceleration data and feed it to an inertial navigation model
- Continuously capture cellphone signal power levels and any other data available and feed it to triangulation model
- Display and store captured data locally
- Transmit captured data in real time over 3G/4G network

Implementing a full modular system such as this will permit the collection of data and experimentation under different situations in an almost real-world environment and also keep the system extremely easy to extend. Every functionality previously stated should be fully automated in order to promote uninterrupted data capturing for long periods of time. A state construction model may later be chosen to be applied as an extension to the real time software functionality (pre-processing) or to collected data (post-processing).

The real time data transmission towards any external service provider (Cloud or storage server) will initially be developed as a plain TCP or UDP timestamped packet/datagram encapsulation in order to verify any 3G/4G network performance issues. Later down the development line a suitable protocol will be chosen in order to encapsulate the data correctly for M2M communications.

Finally, in order to have an easy way of verification for in-vehicle real time interaction between the driver and the device a single LED or/and a buzzer will be added to the device that will enable any basic Human-computer interaction scheme to be studied.

VIII. Conclusions And Discussion

In the current paper, the MANTIS approach that will provide a higher level of intelligence in next-generation transportation systems was presented. MANTIS will exploit the data collected from the vehicular networks (vehicle, passengers, cargo) providing a framework for the development of heterogeneous applications in intelligent transportation systems with the scope of improving road safety and achieving efficient and ecological routing. MANTIS applications will allow the identification of accidents, initiating the execution of automatic emergency calls in real time, and also, provide information about road events and pattern analysis based on big data analytics techniques. For future steps, the prototype system of MANTIS described above, will be finalized and tested in real life conditions in Attikes Diadromes.

Since MANTIS is by definition a system that will “move” a massive amount of data containing both vehicle and human states it is imperative that privacy protection policies be considered and applied in the final system.

Firstly, the data availability should be considered, as there are ethical implications on who and what data is permitted to have access to. A good example that may raise exceptional questions is: will the system make available the vehicle speed data to police authorities? Will this cause any psychological burden to the drivers trying to obey to speed limits at-all-times increasing in such way the chance of causing an accident or will this act as an accident prevention mechanism?

There are also numerous occasions where the collected data may be extremely valuable for 3rd party organizations, such as a driver’s “safe driving level/habits” data to insurance companies.

There are methods of encryption well established and developed for automotive usage [34] that can hide the generated data from unauthorized access; there are also privacy models available that may help the system to discriminate between “sensitive” and “public” data [33] but at the end the question that must be answered is “How much privacy are we willing to sacrifice in order to achieve a greater safety level”.

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