SDN Based Cloud Platform for Smart Vehicles

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Abstract- Over the past few years, the advances in wireless communications, the expansion of cloud computing applications and the implementation of intelligent terminal equipment, forced vehicle manufacturers to rethink the role of advanced Information and Communication Technology (ICT) in the vehicle industry. The process of designing, developing and deploying the new, smarter concept of vehicle management started by realizing the power of the collected data to improve vehicle services, to enable an integrated, effortless service experience, to engage with the drivers and implement the solutions for the well-being of all traffic participants. In this paper, we first define the key requirements for the integration of Smart Vehicle Computer System (SVCS) with cloud assisted automotive applications. Further, based on these requirements, we design a flexible and scalable cloud platform based on implementation of software defined networking into an architecture called Smart Vehicle to Cloud Integration Architecture (SVCIA). The goal is to provide a dynamic allocation of resources adjusted to the user needs and an easy implementation of new services, which makes driving safer and more comfortable for users. The validation of the suggested solution has been done through simulation, where we used a cloud application based on Dijkstra algorithm in order to dynamically route the traffic and avoid congestions. The obtained results show that the use of this kind of solution can significantly improve drivers' satisfaction and safety during the ride.

Keywords- cloud*; *Smart Vehicle to Cloud Integration Architecture (SVCIA); Smart Vehicle Computer System (SVCS); Software Defined Networking (SDN); Dijkstra algorithm.

I. Introduction

The future of the automotive industry is closely related to the development of advanced electronic systems and their integration with the applications on the cloud via Internet technology [1][2]. It is a part of new Internet of Vehicles (IoV) paradigm and the goal of this integration is to raise the level of intelligence of vehicles and to realize users' requirements [3]. They can generally be divided into two categories:

- The requirements of drivers to realize quality Information Systems (IS) and to ensure effective circulation of information necessary to improve traffic safety and efficiency.
- The passengers' need for greater comfort during the ride (vehicle as an office, entertainment), which means access to high-speed Internet.

The realization of these requirements implies the design and deployment of complex and intelligent computing systems in cars: Smart Vehicle Computer Systems (SVCS). Their implementation includes integration of the Geographic Information System for continuous vehicle tracking, traffic monitoring and other data collections, such as effective traffic signalization, weather conditions, etc. [4]. SVCS applications and services are provided by different communication technologies, computer platforms, sensors and other active devices [5][6]. Therefore, it is a major technological challenge to network the vehicles and to implement new telematics applications. From our point of view, the platform should enable vehicle networking with a built-in module for autonomous decision-making and control in the SVCS. We are convinced that the development of smart systems for networking of vehicles is crucial for a large-scale introduction of intelligent solutions; a prerequisite is a cloud environment [7]. The advent of cloud technologies, more than ever, creates the possibility to substitute conventional methods of collecting and processing sensory information approaches by: 1) decentralization of detection and data collection, assuming that sensor data are detected and collected from different locations; 2) collecting information and resources from the cloud; 3) analytics of those data; 4) ad-hoc exchange of detected information with other vehicles in the case of breakup of cloud connectivity and their subsequent forwarding to the cloud in order to update the existing databases; 5) elastic provisioning of secure access for a specific cloud provider, while the IP address of the link provider is constantly changing due to soft hand-off between base stations. It is assumed that the users can scale resources up or down in real-time based on requests.

We analyze how to enable the applications to use programmable dynamic interfaces to control and allocate network resources in order to differentiate the needs of users (such as SVCS) and the data types [8], and we propose the usage of Software Defined Networking (SDN) as a new solution for vehicle networking. This solution is a new and flexible combination of several existing contributions, including:

- Solution for providing the continuity of service,
- Ad-hoc communication between vehicles, important in case of interruption of the communication link between SVCS and traffic cloud,
- Centralized management and optimization of network resources, thus guaranteeing the reliability of services

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(the concentration of routing information in the controller provides fast traffic redirection in case of failure, choosing the alternative route with minimum cost).

- Dynamic subscribing - dynamic user registration according to economic criteria (service on demand),
- Scalability, achieved by adding the SDN controller.

The remaining of the paper is elaborated as follows: Section 2 provides an overview of the research in the automotive industry with a focus on the field implementation of advanced ICT in vehicles and traffic management. In Section 3, we describe the proposed design of SDN-based architecture for vehicle to cloud integration. This concept, based on the SDN paradigm as an emerging technology, is described in Section 4. Section 5 provides an evaluation of the proposed solution from the traffic prediction standpoint. Section 6 concludes the paper and gives some details about how to reliably predict traffic.

II. RELATED WORKS

Today, there are many researches which deal with different aspects of application of advanced ICT solutions in the automotive industry and in traffic predictions. In ICT technologies, there are many new solutions. Different architectures are being developed, and the elements of an Intelligent Transport System (ITS) are being described. A large number of research papers have a goal to improve the implementation of Internet of Things (IoT) applications for smart traffic. Wibowo et al. [9] provide a multi-criteria analysis used to calculate the “smartness index”, which represents the ability of the transportation system to help with a particular problem in order to develop a good strategy for a solution. Applications that solve traffic problems are often part of other projects, such as „smart city“, which has as goal to improve the quality of life in the city environment. Examples of such applications include:

- Experimenting Acoustics in Real environments using Innovative Test-beds (EAR-IT) sub-project [10], in which the focus of the research is the analysis of the sound coming from the surroundings, with the aim to draw a conclusion about the traffic density, deadlock or occupancy of the lanes. A couple of hundreds of units have been installed around the city; they are connected to a central processor in order to process the sound. These units have microphones and computers installed in them, and they are connected to sensors, which allow precise location of the coming sound. When cars with priority pass are observed, the system has the ability to keep track of the siren and to locate the vehicle, and this information is used to facilitate the passage of the vehicle with priority to the desired destination.
- Applications which are developed to show the number and position of currently available parking lots in the city [11].

Some research papers point out the development of a smart transport system based on IoT solutions, which helps in solving traffic problems, and even enables vehicles to drive without human intervention (Google Car project [12]). The main idea in these papers is to use advanced solutions efficiently, to collect information about the location (for example, the number of moving vehicles in order to estimate the duration of travel, travel conditions, car accidents, etc.) in order to detect risks, to determine the best path to destination, to reduce the emission of harmful gases, etc. Pyykönen et al. [13] present a system based on the application of Road-Side Units (RSUs) for monitoring the connection between the sensors placed in vehicles and databases [13]. This system is collecting data, with adequate accuracy, from RSUs and moving vehicles and stores them in databases. This information is forwarded to the drivers, in order to adjust the speed, and to employees in the road service in order to easily locate the part of the road which has to be fixed. There are also papers which describe quantifiers for determining the current state in traffic. iRide [14] is an application, which enables real-time information coming from sensors located near the road. This information is being forwarded to the server, where it is processed and sent to the drivers to enable them to learn about the road conditions. Collecting information is a process that requires accuracy and takes into account a dimension of several timelines. This is the reason why Vehicular Adhoc Networks (VANET) are a part of this research and they do not only include communication between vehicles, but also communication between vehicles and the infrastructure. In [15], the authors propose a Systematic Management of Road Traffic (SMaRTDRIVE) application for mobile phones and smart systems to help with traffic prediction. It has an aim to help vehicles with priority pass. Vehicles are equipped with On Board Unit (OBUs), which are used to collect data about the status of vehicles from different sensors. The server contains a database and a Web application. The SMaRTDRIVE application can also be used by pedestrians. By clicking the button, they can report accidents on the road, congestions, or some other problems. The OBU unit placed in the vehicle can automatically detect the accident in which a car participated and informs the services. RSU has a task to control traffic signalization. Many papers explain the usage of „smart phones“, and techniques such as “mobile crowdsourcing”. In [16], the authors show how this technique can be successfully used in traffic for finding the optimal routes, where the ranking of a route is done by many users. In order to get the best results, when finding of optimal routes, the crowdsourcing technique is being used in combination with other algorithms.

III. DEVELOPING A PLATFORM FOR INTELLIGENT VEHICLES

The main prerequisite for the implementation of different applications, which should enable drivers to manage the vehicles more efficiently, is to ensure the reliable transfer and storage of data from the related vehicles and from the environment, to the location where they are installed. We believe that the cloud as a centralized location for storing a large amount of data with implemented applications provided by Telematics, Infotainment, Navigation, Fleet management and other services is an excellent location and solution. That is why the goal of our research is to develop a new intelligent platform that would enable the use of mobile network services (3G, 4G, and future 5G) to store and analyze the data from the connected cars. From the spatial aspect, we introduce a concept of four-layered hierarchical architecture, as shown in

Figure 1. The proposed concept of hierarchical SVCP architecture in the spatial sense consists of four different layers, described as follows:

- In the layer of vehicle clients, we are focused on three key areas:
  - monitoring the vehicles in motion,
  - internal and external sensing in order to collect the information which is needed for the prevention of failures, for improving safety in traffic,
  - internal and external sensing for the realization of solutions for the efficient interaction between the driver and the passenger with the embedded computer platform.
- At the transmission layer, we propose a solution which consists of a secure channel for information delivery from cloud through the available mobile network (3G, 4G, 5G) and ad-hoc solutions for resource and safety information shared between vehicles. For example, the information about an accident can be transmitted to the drivers who are near, to be warned in time about the situation on the road.
- The platform layer provides vehicle intelligence through the usage of different interfaces in order to take a great amount of differently structured information, which is collected from the internal and external sensing and provide the customized services and specialized applications for the drivers and passengers. At this layer, the content of video cameras is transmitted to the server via the nearest available network access to the Internet cloud. Virtual machines with significant resources (processor, memory, and network bandwidth) at cloud servers guarantee the quality of service. Different users, such as drivers, traffic controllers and passengers, can collect information from the multiple cloud services via different interfaces.
- The application layer enables the applications that include distribution of information about traffic congestions, the availability of parking spaces in certain geographic locations.

The core element of the platform is the internal (in-vehicle) virtual network, called SVCP, which provides the "smart" attribute [4]. A vehicle at the micro layer provides an efficient system for the real time collection and distribution of information from the vehicle and from the environment. This network consists of 1) different types of sensors, 2) a computer with a sensor aggregator which can perform a number of things in the computer itself like, store raw data locally, aggregate the raw data into data sets that can be more readily used, etc. and 3) a virtual switch that communicates through high data rate wireless communication links (e.g. Long Term Evolution (LTE) module) with the SDN controller on the cloud by the Open Flow protocol (see Figure 2.) [4]. The controller provides dynamic resource allocation and traffic routing in interaction with cloud network applications. It is designed so as to provide simple and efficient communications between virtual machines and the internal network in the vehicle, including humans and intelligent sensor devices. Virtual machines process the data collected on sensors, providing fast feedback to the vehicle user. Google economist evaluate that more data are being produced every couple of days now than in years before

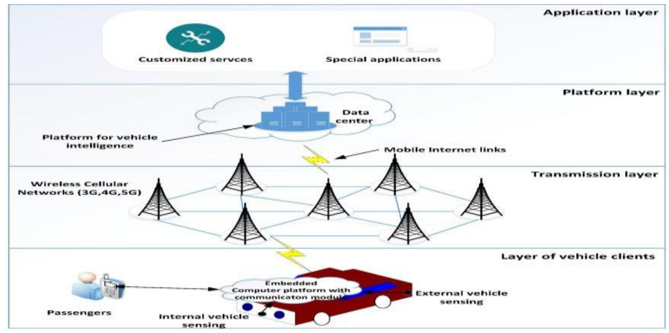

Figure 1. Concept of four-layered hierarchical architecture

2003. Some experts expect data volumes to reach 35 zettabytes by 2020. In 2013, 1.7 million billion bytes of data per minute were being generated globally. Due to a number of different driving technologies, we have explosive growth in data. The raw data, which is diverse, structured and unstructured in nature, is being sent to the cloud, where Big Data analytics correlate enormous amounts of data collected from a multitude of sources in real time, including millions of vehicles, drivers, weather, traffic, producers of parts (of types, windshields, bumpers, etc.) and other data in parallel. The relevant results of this Big Data analytics will be sent back to each vehicle in due time and either communicated to the driver or to the vehicle controlling algorithm [17].

IV. SVCP ARCHITECTURE SUPPORTED BY SDN BASED TRAFFIC IN CLOUD

In this paper, we design the SDN based SVCP architecture to provide more service contents (e.g., real-time traffic information, VPN service to the company location, gaming, etc.) for drivers, passengers and for better traffic control. The essential remark is that only SDN is responsible for central coordination of the quantity, speed and quality of data delivery, independently of the requests from the end user. The application of this platform significantly affects the safety, comfort and efficiency of driving. In order to explain the advantages of this platform, we have to clarify the processes that take place both locally and in the cloud. Different types of sensors are installed in vehicles, performing continuous measurements of a wide range of parameters, such as the state of individual functional units of the vehicle, the environmental conditions around the vehicle, the surrounding traffic signs, and the speed of vehicles coming from both directions, the state of health of the driver and passengers [18]. Usually, the degree to which vehicles are equipped with intelligent sensor devices as well as the quality of sensor devices vary. Therefore, it is justified to question the validity and extent of data obtained from the sensors. A particular challenge is the fact that from the available sample data, technologically limited local data processing systems, and with the available data analytics on board, it is not often possible to provide all the relevant information. Therefore, in the solution proposed in this paper, the emphasis is given to connecting the internal network to the cloud and processing them there as a part of evolution towards 5G [8].

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The data arrive to the cloud at a high speed, proportional to the increase of the number of vehicles on the road. The amount of this data is great, and they are characterized by diversity and often structured differently. The result of the arrival of large amounts of data to the cloud is the formation of a much more representative data sample. The more precise data can be obtained in real time, with the important addendum that information is extracted and delivered to the vehicle using advanced Big Data analytics that no local system can observe individually. An important advantage of applying this solution is that this extra information can significantly improve the safety and efficiency of traffic, despite the fact that there is no expressed demand for it by the end user. By implementing SDN solutions with a centralized view on the system of networked vehicles, the information obtained by Big Data analytics is forwarded to local systems in vehicles even without the request message sent by the protocol on the user side. Based on this information it is possible to predict the movement of vehicles in the near future, the possibility of incidents on the road (e.g. due to a malfunction of the vehicle) and perform pro-active collision avoidance [8]. The information generated in the cloud can be of great importance for road safety and more efficient regulation of traffic on the roads. Their timely distribution to large groups of users is, therefore of paramount importance. This imposes the need for the dynamic changes in the network in order to provide the necessary resources since there is the redistribution of available network resources. Traditional IP networks are not able to provide the necessary dynamic, because any change in the network requires additional time and commitment of the human factor. Troubleshooting dynamic allocation of resources is closely linked with the problem of a more flexible traffic management, which requires that the IP network has brought a greater degree of programmability. For this reason, we have implemented SDN networking technology to help ensure a higher degree of automation in terms of the allocation of the necessary resources and more flexible traffic. The reasons for the occurrence of traffic stoppers may be different (August humidity, defects in vehicles, etc.) and they can cause the creation of kilometers long queues. The analysis of the data from the field and by applying efficient algorithms for prediction, the cloud can timely calculate the size of traffic stopper that could arise in the foreseeable future. To avoid the problem, the information is moving towards a concrete road in order to comply with some of the criteria (shortest path, minimum load on the road, etc.). This requires immediate changes in the configuration of the network, which are necessary for the dynamic allocation of bandwidth to users that can be provided only by the SDN controller to significantly affect the size of the plug and efficiency of traffic, which is shown in Figure 3. The vehicles can exchange information with the traffic infrastructure surrounding, which is very important in the case of failure of the network communication with traffic cloud, in order to avoid eventual accidents on the road. It is possible to establish ad-hoc, point-to-point or point-to-multipoint wireless communication (VANET) within a particular cluster [4].

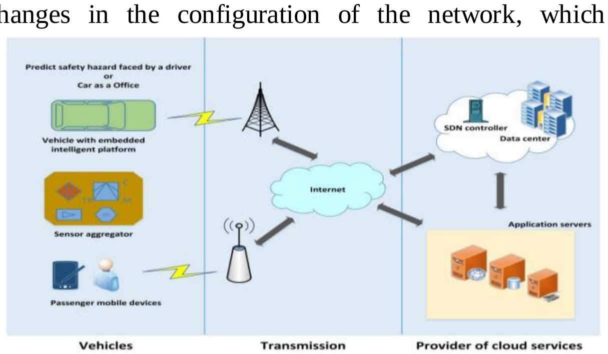

Figure 2. Concept of Smart Vehicle Computer System

V. SCENARIO FOR CLOUD SUPPORTED APPLICATION

In this paper we have done a validation of a suggested solution, with an application scenario on how to avoid traffic congestions on the road in cases when accidents occur.

In the previous section, we have proposed the architecture, and in this section we are evaluating one of the possible applications, dynamic vehicle routing, which is based on the earlier mentioned architecture. The main idea is to perform parameter minimization selected by the user to reach the desired destination. In defining the criteria for routes comparison, we started with predefined parameters, which describe each road section: length and maximal speed allowed.

We suggest an algorithm for realization, which will predict traffic using cloud technologies. Suppose that the traffic network which we are observing consists of 7 areas (theoretically it should be n areas: A1, A2…A7 which are shown in Figure 4.) Inside each area, we have more sections of the road. Each section can be characterized by different parameters:

- Quality of the road (whether it is a service, residential, tertiary, secondary or primary road) from point a to point b, it is denoted by Q(a, b). By primary road we think of highways, secondary roads are main roads in the city, tertiary are roads that lead to secondary roads, residential are roads through settlements and by service road we think of narrow roads which lead to residential roads. Each one of these roads has predefined speed limitations.
- Length of the section (road) expressed in kilometers-d(a, b).

The parameters of the quality of the road can have one of the values from the next set:

$$Q(a,b)\begin{cases} 0, & service\ road \\ 0.25\ , & residential\ road \\ 0.50, & tertiary\ road \\ 0.75, & secondary\ road \\ 1, & highways \\ +\infty, & unused\ road \end{cases}$$

The system starts to work when the event happens and SVCS sends information to traffic cloud. The undirected weighted graph is formed. If the road is not in the function or if there was an accident a value of the parameter Q(a,b) is set to infinity. Vector A (A1, A2… A7) is the range of areas which is shown in Figure 4. Each area consists of nodes collection (for example A1 has nodes S1, S2… Sn). For every area we continuously calculate weights of the path W(w1, w2,…, wn). The weights of the road should be calculated for every path. We are using Dijkstra's algorithm in this paper,

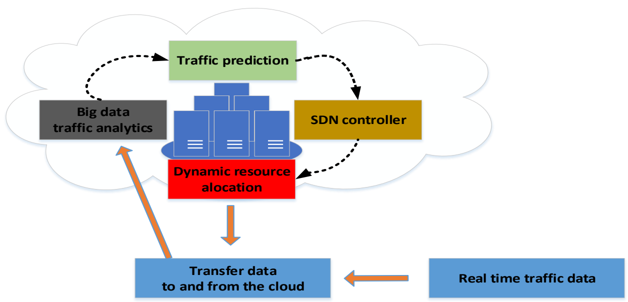

Figure 3. SDN platform for dynamic resource allocation on the cloud

which is adjusted to our needs. Dijkstra's algorithm finds the shortest path between the nodes in the graph, which are represented with different weights listed above w(a,b). The vector of weights is as follows:

$$W = w(a, b)$$

The weighted path can be expresses like a function:

$$W = Q(a,b)+c\cdot\frac{1}{d(a,b)}$$

Where c is a constant used for scaling, and d represents distance between points a and b.

Let us assume that we have a road system as it is shown in Figure 5. It is represented as a connected, undirected and weighted graph, with eight nodes. The weights are assigned with respect to the quality of the road Q(a,b). A user wants to find the shortest path from node A to node H. According to Dijkstra's algorithm, the user starts from the node A and is taking into consideration the paths to the remaining nodes. Since the nodes B, C and D are the neighbors of the node A, new ordered pairs are assigned to nodes B, C and D, respectively. By using the same idea, the algorithm moves through the graph and after a few steps the node H is reached. Analog to this, a user can choose other parameters (d(a,b), w(a,b)). In reality, the best road is not always the highway. In some occasions city road is a better choice, because route can be shorter than the route going along highway. If an accident occurs, our algorithm iteratively calculates a new route. The map was extracted from OpenStreetMap [19] which is a free editable map of the world. For experimental purposes, we have used the map of the University of Novi Sad campus, where the fluctuation of traffic is huge and there are often big congestions. It is very important to redirect cars through different paths in order to reduce the possibility of congestions.

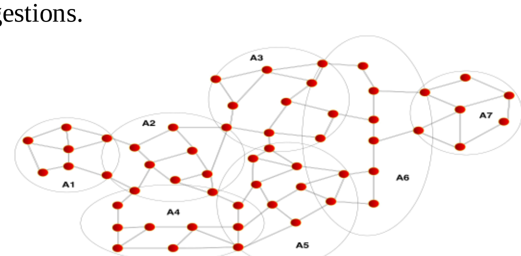

Figure 4. Range of areas

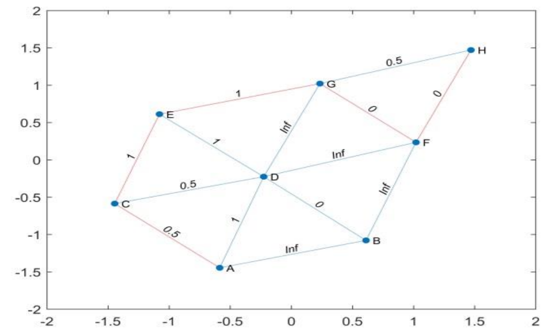

Figure 5. Example of road network

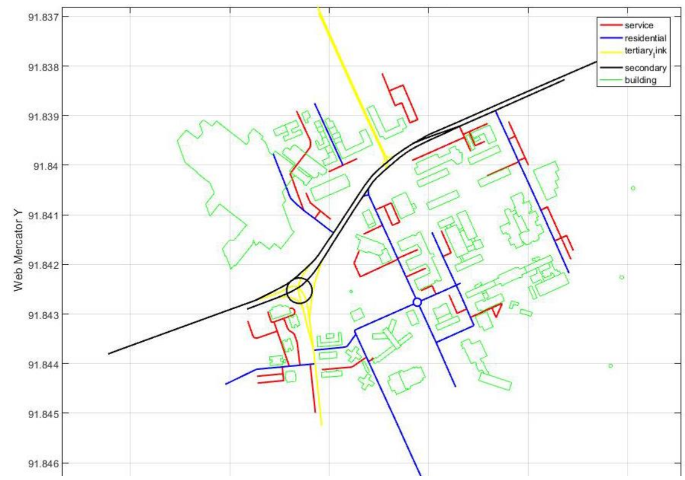

Figure 6. University of Novi Sad

Figure 7. Algorithm decides on the best path from starting to ending position

The model of the campus is shown in Figure 6. Taking into consideration that we have two possible routes from starting position to ending position, we apply our algorithm, and based on the assigned weights, the optimal route is calculated. The optimal route is shown in Figure 7. If an accident or congestion occurs, the cars are redirected to other route consisting of residential road.

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VI. CONCLUSION

The usage of advanced ICT enables an easier integration of cyber-physical equipment in cars with the traffic cloud and provides enormous possibilities for the fast development of intelligent transport systems. In this article, the analysis is done, we provide a brief review of existing solutions in this field, and a new concept of an integrated platform for smart management of cars is proposed. We provide a detailed explanation that a basic concept consists of the applications for efficient management of cars, which are supported with the cloud, and we provide an explanation of the components, which affect the Quality of Service (QoS). In the end, in order to do a validation of suggested solutions, we have proposed an application scenario for the dynamic routing of traffic in cloud with a goal to avoid traffic congestions on the road in cases when accidents occur. Our belief is that SDN based traffic cloud will attract enormous attention from researchers in the near future, in order to ensure an efficient management of traffic, greater security and comfort for all the participants.

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