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Survey on Software Defined VANETs

Sara I. Boucetta, Zsolt Csaba Johanyák[1], László Károly Pokorádi[2]*

[1] Department of Information Technology, GAMF Faculty of Engineering and Computer Science, Pallasz Athéné University, Hungary
[2]Institute of Mechatronics and Vehicle Engineering, Óbuda University, Hungary

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Abstract
Modern vehicles are equipped with a wide variety of sensors, on-board computers and different devices supporting navigation and communication. These systems aim the fulfilment of various demands on the improvement of traffic safety, traffic/route optimization, passenger, comfort, etc.
Inter-vehicle and vehicle-infrastructure communication plays an important role in this process, which resulted in the birth of Vehicular Ad-hoc Networks. In t*he first part of the article, the key ideas of VANETs and their communication types* are presented, then *the most important features of vehicular ad-hoc networks are discussed followed by typical application types and actual characteristic research directions. The second part of the article focuses on Software Defined Networking and its application possibilities in VANETs emphasizing the benefits they can provide.*

1 Introduction

The aim of ambient intelligence is to create an intelligent and immediate user space integrated into the walls of our homes, offices, roads, and cars. The implementation of this new concept should be invisible and it should blend into our everyday environment, and should be available when we need it.

One of the applications of this concept is to provide our cars and roads with systems that make roads safer and the time spent on the roads more user-friendly. This application is a typical example of the so-called Intelligent Transportation System (ITS), which aims to improve the safety, efficiency and conviviality of road transports using the new information and communication technologies (ICT).

As an integral part of an ITS system, inter-vehicle communication is continuously evolving, and since vehicles travel at high speeds, it is not possible to establish an infrastructural network with infrastructure between them. Although the ad-hoc solution seems to be the most judicious one, but the communication protocols of Mobile Ad-hoc Networks (MANET) are not adaptable to vehicles which are forced to follow a precise route during their movements on the one hand and on the other hand their movements are so fast that there is a high rate of connection and disconnection in the network. This problem resulted in the birth of Vehicular Ad-hoc Networks (VANETs) [1].

VANETs are now a reality that supports a wide variety of new services and protocols. However, there are still challenges in the deployment of VANET applications such as unbalanced flow traffic among multi-path topology, and inefficient network utilization [2]. Vehicular Ad-hoc Networks allow communication among vehicles (V2V) and between vehicles and fixed infrastructure (V2I), aiming to support a wide range of services and applications to make travel experience pleasant, safe, and informed. Applications envisioned for VANETs vary from traffic conditions and accident warnings, to

* Corresponding author.
E-mail address: boucetta.imene@gmail.com

infotainment services such as live video streaming and gaming, etc. However, there are some serious technical challenges in VANET communication as well. They are mainly related to the high dynamicity and volatility of the vehicular environment.

To overcome these challenges a promising option is the application of Software Defined Networking (SDN). It is a dynamic, manageable, cost-effective, and adaptable architecture, seeking to be suitable for the high-bandwidth, dynamic nature of current applications [3]. SDN decouples network control and forwarding functions, enabling network control to become directly programmable and the underlying infrastructure to be abstracted from applications and network services. The flexibility of SDN makes it an attractive approach that can be used to satisfy the requirements of VANET scenarios. Applying SDN principles to VANETs will bring the programmability and flexibility that is missing in today's distributed wireless substrate, while simplifying network management and enabling new V2V and V2I services.

In this survey, first, we present the most important features of VANETs in Section 2 including the available communication types, challenges, applications and future research directions. After giving a short introduction in SDN concepts in Section 3 the application possibilities of SDN in VANETs are presented emphasizing the benefits they can provide. Finally, some conclusions and remarks are discussed in Section 4.

2 Vehicular Ad Hoc Networks

Vehicular ad hoc networks (VANETs) are considered as a class of mobile ad hoc networks (MANETs), where mobile nodes are vehicles equipped with embedded computers, network interfaces and sensors. Vehicles can communicate with each other (V2V) or with stations (V2I) along roads (to request information for example). These stations can be linked together (infrastructure-to-infrastructure - I2I) by wired or wireless links and are also connected to other types of networks where several services can be envisaged.

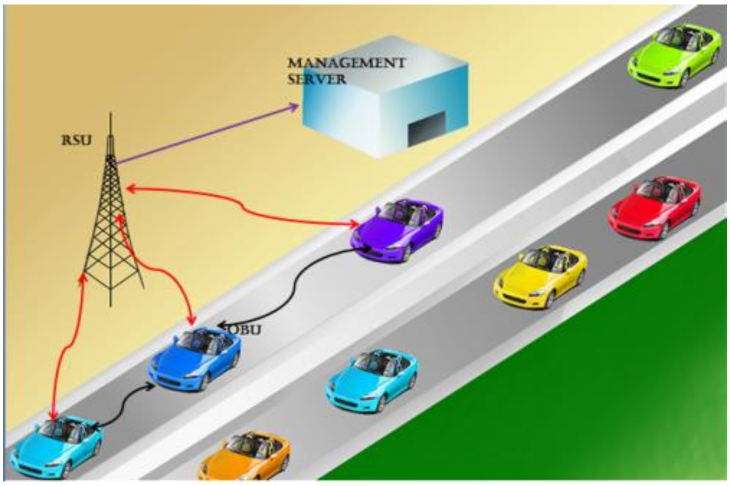

Figure 1. Example of a VANET network [4]

2.1 Communication in VANETs

The services offered in VANETs distinguish two possible types of communication, i.e. Vehicle to Vehicle Communication (V2V) and Vehicle to Infrastructure Communication (V2I), which are described shortly in the following two subsections.

2.1.1 Vehicle to Vehicle Communication (V2V)

The purpose of the inter-vehicle communication is to transmit the relative information of the traffic on multiple jumps to a group of receivers [5].

Figure 2. Inter-Vehicle Communication (Multi-Hop) [6]

2.1.2Vehicle to Infrastructure Communication (V2I)

The Vehicle-to-Infrastructure communication represents a single-hop broadcast where the roadside unit (RSU) sends a broadcast message to all nearby equipped vehicles [5]. Figure 3 illustrates the communications between Vehicles and road infrastructure.

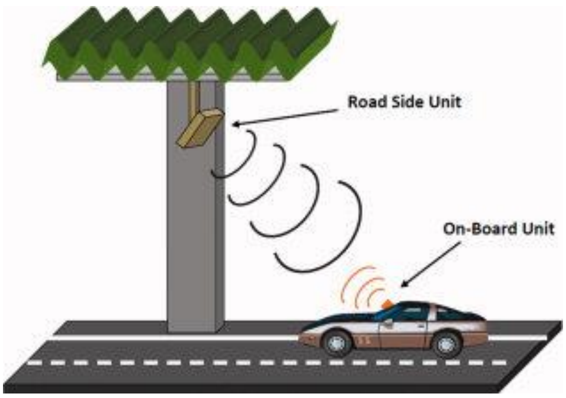

Figure 3. Vehicle to Infrastructure Communication (Single-Hop) [8]

The combination of these two types of communication provides an interesting hybrid communication opportunity. Indeed, since the scopes of the infrastructure are limited, the use of vehicles as relay makes it possible to extend this communication range. For economic purposes, avoiding multiplying the terminals at each street corner, the use of jumps by intermediate vehicles can become very important [9].

2.2 Characteristics and Challenges of VANETs

Achieving VANET networks dedicated to embedded applications in vehicles requires techniques and protocols that take into account the uncertainties and requirements of these networks. In addition to the characteristics of conventional mobile ad hoc networks, the vehicular networks arrive with attractive configurations, as presented below.

- **Unlimited transmission and calculation power:** The theoretical range of communication is 1000 meters, but in practice, it is around 200 meters [10]. The main advantage of the applied Dedicated short-range communication (DSRC) is the very low latency, below 100 milliseconds, which is ideal for security applications that require a delay in this range. The power of the vehicles is not a significant constraint, as in the case of conventional ad hoc networks or sensors, since the node (vehicle) itself can provide the power required for calculation and transmission equipment.
- **Great calculation capacity:** vehicles can have significant means for calculation without having any energy or weight constraints as is the case of laptops, smartphones, tablets and other mobile equipment.
- **Predictable mobility:** In traditional mobile ad-hoc networks it is difficult to predict the mobility of nodes, whereas vehicles tend to have very predictable movements that are (usually) limited to road structure. Information about the road structure is often provided by positioning systems such as GPS and card-based technologies. Given the average speed, the current speed, and the road trajectory, the future position of a vehicle can be predicted. However, vehicular networks have to deal with certain characteristics that make it difficult to design protocols capable of dealing with all these problems.
- **A large-scale network:** Unlike most ad hoc networks, which usually assume a limited network size, vehicular networks can extend to a very large scale relatively to the entire road network and thus include many participants.
- **High mobility:** One of the most important aspects of vehicles is their high mobility with speeds of up to 200 km/h in a highway environment, thus making the network topology highly dynamic. The density of the nodes can be 1 to 2 vehicles per kilometre on a route of less traffic, while in urban areas speeds cannot exceed 90 km/h with high traffic densities especially during peak hours, which makes the design of certain protocols sensitive and specific to each configuration.
- **Partitioned network:** Vehicular networks will be frequently divided. The dynamic nature of traffic can generate a large inter-vehicle distance in sparsely populated cities, and consequently in several clusters isolated from the nodes.
- **Limited bandwidth:** the nature of the radio link does not allow to increase the bandwidth infinitely, so communication applications must consider this limitation.
- **Network topology and connectivity:** Network traffic scenarios are very different from conventional ad hoc networks as vehicles move and change their positions constantly, so the scenarios are very dynamic. Therefore, the network topology changes frequently with the change of links in terms of connectivity. Indeed, the degree to which the network is connected is highly dependent on two factors: the range of wireless links and the fraction of participating vehicles.

2.3 VANET Applications

With the rapid development of new techniques in vehicular ad hoc communications, various new applications are emerging. VANET applications can be categorized into three major groups: prevention and road safety, traffic optimization and passenger comfort.

a. **Prevention and road safety:** VANETs can significantly improve road safety by alerting the driver about dangerous situations. They also allow to enlarge the field of perception of the driver to all the vehicles with which they can communicate.
b. **Traffic optimization:** Automobile traffic can be greatly improved by collecting and sharing data collected by vehicles. A car may, for example, be warned of a traffic jam, a rockslide or an accident before it approaches it, so that it can avoid the road leading to it.
c. **Passenger comfort:** Vehicle networks can also improve the comfort of passengers, by offering them services such as internet access. For example, VANETs provide the Internet connection to vehicle nodes even in full motion so the passenger can download, send e-mails, view movies online, or participate in INTERNET games. Usually, some dynamic 'Gateways' assigned network-to-Internet are added to the networks, so they can provide messages between the

VANET and the INTERNET. These applications use unicast routing as the primary communication method.

Figure 4. VANETs communication and applications [11]

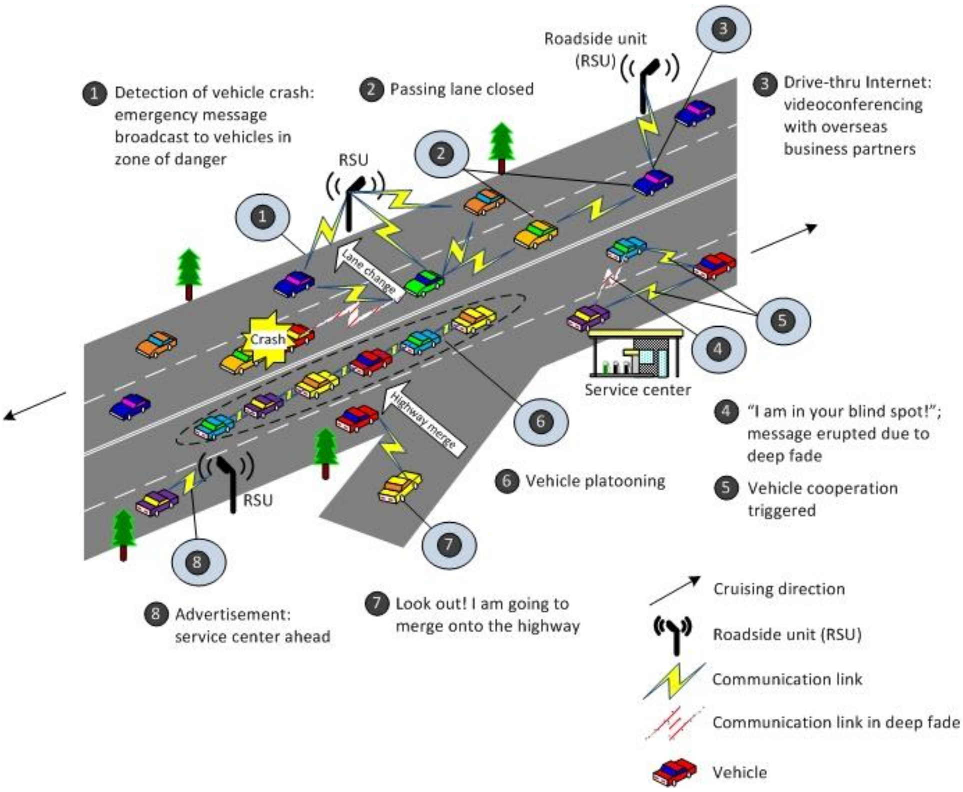

Figure 5. Infotainment and safety service support in VANETs [12]

2.4 Research Directions in the Field of VANETs

VANETs are open to several areas of research, including safety, vehicle location, routing, and dissemination.

a. **Safety**: considering the sensitivity of the VANET applications, an intrusion of a malicious vehicle would have serious consequences for all the interconnected vehicles.
b. **The location of vehicles**: if one of the vehicles in the network is to be located (for example in the case of an accident), the others must be informed about its position. The problem is that not all vehicles are equipped with a satellite tracking system (GPS), it is for this reason that a locating mechanism without using the GPS is necessary.
c. **Routing**: the main feature of VANETs is that they quickly change topology because of their high mobility, which makes routing a very difficult problem to manage.
d. **Dissemination:** One of the problems of VANETs is that each vehicle communicates with all those in its coverage area, which leads to a deterioration in the quality of service (QoS) due to the increase in the number of vehicles, Information redundancy, data loss (collisions), network congestion, or the Broadcast Storm problem.

3 Software Defined Networking

The Internet is based nowadays on the distributed control and transport network protocols running inside the routers and switches that allows information to travel all around the world. Despite of their large adoption, traditional IP networks are challenging and hard to manage [13]. To express the desired high-level network policies, network operators need to configure each individual network device separately using low-level and vendor-specific commands.

In addition to the configuration complexity, network environments have to face the dynamics of faults and adapt to load changes. Automatic reconfiguration and response mechanisms are virtually non-existent in current IP networks. Enhancing network policies in such a dynamic environment is highly challenging.

Actual networks are also vertically integrated. The control plane (that decides how to handle network traffic) and the data plane (that forwards traffic according to decisions made by the control plane) are bundled together inside the networking devices, reducing flexibility and limiting innovation and evolution of the networking infrastructure. The transition from IPv4 to IPv6 is still incomplete, while in fact IPv6 represented simply a protocol update. A new routing protocol can take 5 to 10 years to be fully designed, evaluated and deployed due the inertia of current IP networks.

The Software Defined Networking (SDN) paradigm introduces a centralized and programmable way of designing networks and was designed to face the shortcomings of traditional networks, such as manual configuration and maintenance of every single device in the network, high latency in path-recovery due to distributed approach, etc.

SDN separates the data plane from the control plane, improving the programmability of the network by external applications. In an SDN-based network, the intelligence is centralized in a network controller, which determines how traffic flows will be forwarded in the network; while network devices (switches, routers) simply forward the packets, following the per-flow rules installed by the controller [13]-[14].

By means of a Southbound Interface (SBI) and a Northbound Interface (NBI), the control plane interacts with the data plane and application plane, respectively. SDN simplifies network management by providing highly dynamic, flexible and automated reconfiguration of the network, more efficient use of network resources, and makes troubleshooting and debugging simple and easy. Thus, the controller becomes the true brain of the network by bringing the following benefits [17]:

- Transforms the network into a resource that can be easily provisioned and programmed.
- Ensures quality of service, regardless of the infrastructure in place.
- Manages the network easily and at a low cost, since network administrators only have to manage parameters and rules, only at the central controller level, and not at the level of each device.

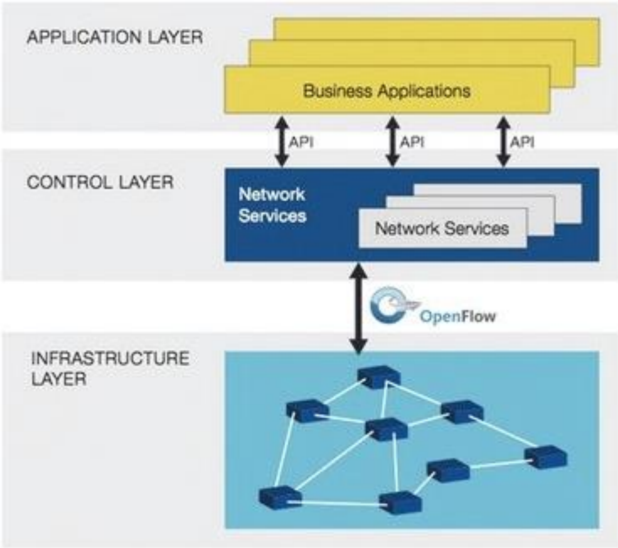

Figure 6. Software Defined Networking (SDN) Framework [15]

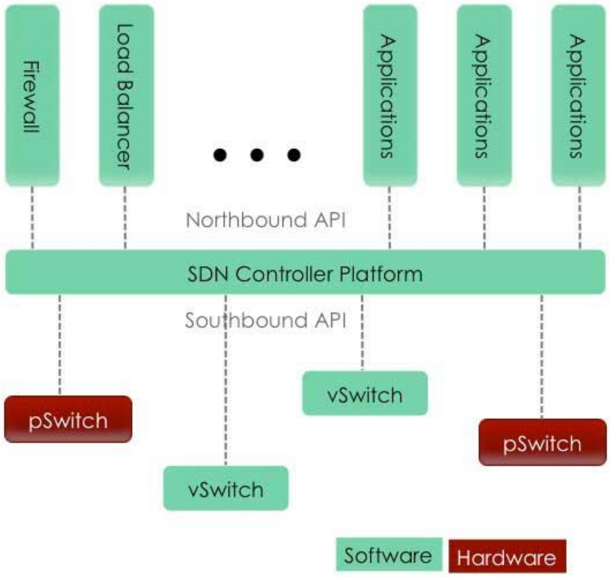

Figure 7. Hardware and software SDN architecture [16]

3.1 Enabling SDN in VANETs

Nowadays, interest is focused on smart mobility, which includes enhancing traffic conditions, travel efficiency, vehicle safety, and passengers comfort while on the road. These latter want to connect to the Internet everywhere on the road, subscribe to a variety of services, and get real-time information about traffic and facilities. These services are mainly provided by vehicular applications, which has to be able to deal with the high mobility of the network environment and consequently with the unreliable connectivity, both in Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. Road Side Units (RSUs) are usually located only at a few critical intersection points with short radio communication ranges. Consequently, connectivity is intermittent: it is often broken and re-established in a different location.

Hence, communication networks must be designed using a totally new approach, designing a new network paradigm that will be structured to minimize the impact of disconnections caused by vehicle mobility and improve reliability of communication in Vehicular Ad hoc NETworks (VANETs), promoting the development of smart mobility. The SDN paradigm is a suitable candidate, and it is expected to result in a change from the way in which vehicular networks were classically operated.

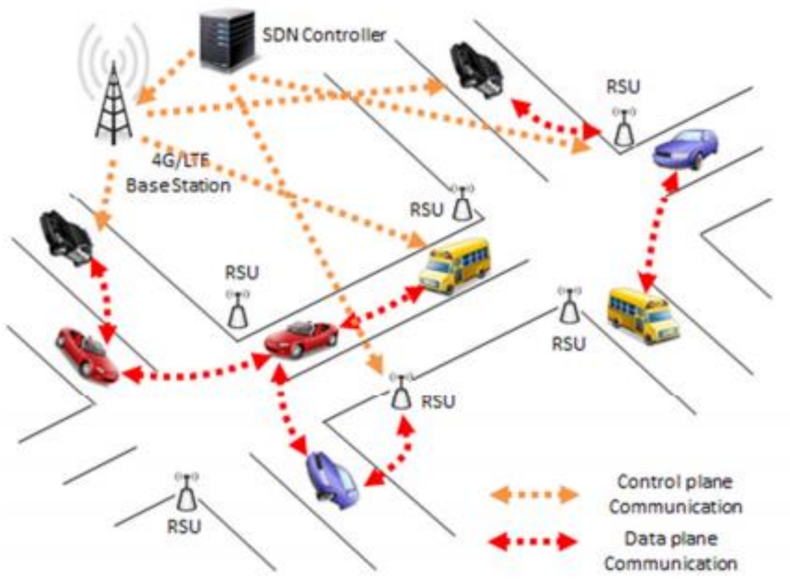

Figure 8. Software-Defined VANET Communications [13]

SDN has emerged as a flexible way to control the network in a systematic way, with OpenFlow as the most commonly used SDN protocol for communication between the SDN control plane and data plane [13]. The flexibility of SDN makes it an attractive approach that can be used to satisfy the requirements of VANET scenarios. Applying SDN principles to VANETs will bring the programmability and flexibility that is missing in today's distributed wireless networks, while simplifying network management and enabling new V2V and V2I services.

3.2 Software Defined VANETs

While the concept of SDN is the separation of control and data plane, there are differences in how a Software-Defined VANET can operate based on the degree of control of the SDN controller. This architecture is classified [13] into three operational modes:

a. **Central Control Mode**: in this mode the SDN controller controls all the actions of underlying SDN wireless nodes and RSUs, it means that all the actions that the SDN data element performs are explicitly defined by the controller, the SDN controller will push down all the flow rules on how to treat traffic.

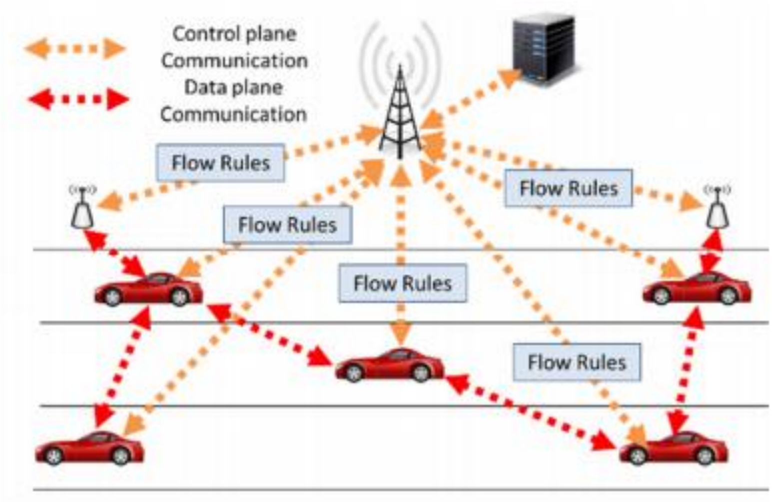

Figure 9. Central Control Mode [13]

b. **Distributed Control Mode:** This is a mode where underlying SDN wireless nodes and RSUs do not operate under any supervision from the SDN controller during data packet delivery. This control mode in essence is very similar to the original self-organizing distributed network without any SDN features, except that the local agent on each SDN wireless node controls the behaviour of each individual node (e.g., run GPSR routing).

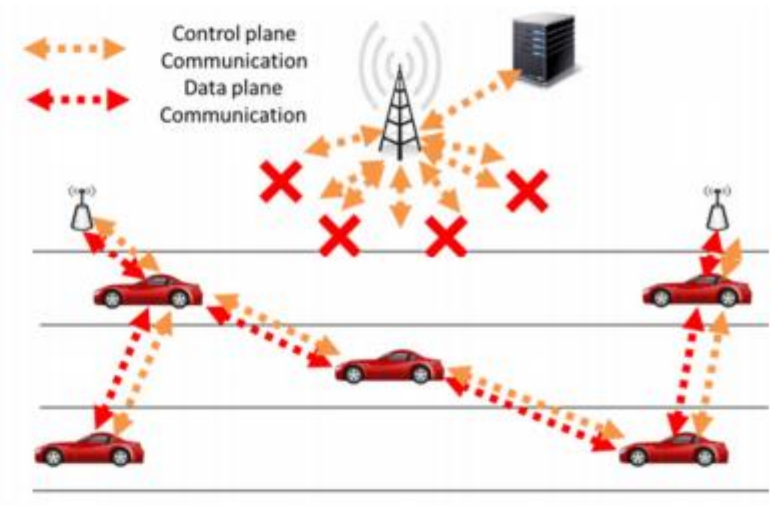

Figure 10. Distributed Control Mode [13]

c. **Hybrid Control Mode:** This mode includes all the operational modes of a system where the SDN controller apply control anywhere between full and none. Figure 11 shows an example, where the SDN controller does not hold complete control, but instead can delegate control of packet processing details to local agents. Therefore, control traffic is exchanged between all SDN elements. One example would be that instead of sending complete flow rules, the SDN controller sends out policy rules, which define general behaviour, while the SDN wireless nodes and SDN RSUs use local intelligence for packet forwarding and flow level processing. In specific, the SDN controller instructs SDN wireless nodes and RSUs to run a specific routing protocol with certain parameters.

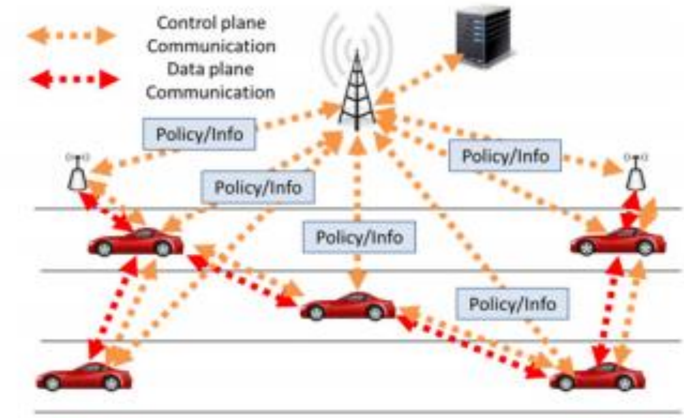

Figure 11. Hybrid Control Mode [13]

3.3 Software-Defined VANET benefits

Benefits of Software-Defined VANETs can be classified into the following three individual areas [13].

a. **Path Selection**: The awareness of SDN allows the system to make more informed routing decisions. For example, in a VANET scenario, data traffic can become unbalanced, either because the shortest path routing results in traffic focusing on some selected nodes, or because the application is video dominant, which occupies big bandwidth on the path. When this situation is discovered by the SDN controller, it can start a reroute traffic process to improve network utility and reduce congestion.
b. **Frequency/Channel selection:** When an SDN wireless node has multiple available wireless interfaces or configurable radios such as cognitive radios, an SDN-based VANET can allow better coordination of channel/frequency usage. For example, the SDN controller can dynamically decide at which time what type of traffic will use which radio interface/frequency. This can be used to reserve channels for emergency traffic for VANET emergency services.
c. **Power selection:** Because of the awareness, an SDN based VANET will have the information to decide whether changing the power of wireless interfaces and therefore its transmission range is a logical choice. For example, the SDN controller gathers neighbour information from SDN compliant wireless nodes and determines which node has a too sparse density and commands all nodes to achieve more reasonable packet delivery and reduce interference.

3.4 Software-Defined VANET services

Based on their benefits many services can be enhanced using a Software Defined VANET [13] as follows.

a. **SDN Assisted VANET Safety Service:** SDN can be used to reserve or limit specific frequencies so that emergency traffic (or otherwise privileged traffic, such as security) uses this reserved path. The difference between this and traditional emergency channels is that reservation in our architecture is configurable dynamically. The SDN controller can assign flows to these channels or remove them based on current traffic conditions and application requirements. This can also be used to offer different level of services based on policies. The way this can be done is by changing rules during an emergency period. Emergency traffic gets priority over the remaining traffic.
b. **SDN-based On Demand VANET Surveillance Service:** Surveillance service for emergency/authority vehicles is another area in which a Software-Defined VANET can be

deployed. The SDN controller simply inserts flow rules for the surveillance data to reach the requesting nodes.

c. **Wireless Network Virtualization Service:** virtualization services aim to provide abstract logical networks over shared physical network resources. The idea is to let different flows choose different radios/interfaces using different frequencies. If the radio frequencies used by each individual network are different, individual networks' traffic are isolated from each other and we have thus effectively sliced the networks and created virtual wireless networks. One method would be the grouping of wireless nodes and RSUs, so each RSU only forwards traffic from a selected group of wireless nodes. Another more advanced method would be to incorporate time slicing. The control of which network uses which radio interface/frequency for which time period is done by the SDN controller, which makes the allocation of network traffic a programmable fashion. Time slicing for efficient OFDM spectrum allocation used for LTE networks can be applied in the Software Defined VANET to support one virtual wireless network per time slot. If multiple radio interfaces are available, multiple virtual networks can be supported in the same time slot.

4 Conclusions

The concept of VANETs have been emerged as a response to a significant demand on ensuring safe and reliable communication between vehicles as well as between vehicles and infrastructure elements (road side units). VANETs are currently receiving increased attention from manufacturers and researchers in order to improve safety on the roads or the proposed assistance to drivers. In the first part of the article after presenting the key ideas of VANETs and their communication types the most important features of vehicular ad-hoc networks have been discussed followed by typical application types and actual characteristic research directions.

In the second part of the article we focused on Software Defined Networking and its application possibilities in VANETs. The key idea of SDN is the centralized and programmable network flow management, which can result in an increased efficiency and decreased management costs. The flexibility of SDN allows it to satisfy the requirements of VANET scenarios, which can bring the programmability and flexibility that is missing in current distributed wireless networks, while simplifying network management and enabling new V2V and V2I services.

There are several directions that are worth investigating in field of software-defined VANET services, such as improvement of the security of emergency dissemination messages, road safety improvement, effective alternative methods when a group of nodes loses connection to the SDN controller, using computational intelligence techniques in optimal dynamical frequency power (range) selection, network virtualization, etc.

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