Towards Software Defined Heterogeneous Vehicular Networks for Intelligent Transportation Systems

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***Abstract*—Recent advancements in the telecommunications and automotive sectors, combining in the form of Intelligent Transportation Systems (ITS), are leading to intelligent connected and autonomous vehicles. At present, IEEE 802.11p Dedicated Short Range Communication (DSRC) and the next-generation cellular networks are considered as the key wireless access technologies for the vehicular networking industry. Nevertheless, none of them are capable of meeting the stringent latency requirements of diverse vehicular safety-critical applications. This paper, therefore, presents an ongoing research work pertinent to software defined heterogeneous vehicular networking architecture for ensuring an extremely reliable and low-latency communication for the safety-critical vehicular cooperative applications and services.**

I. Introduction & Motivation

Over the past few decades, the promising notion of vehicular ad hoc networks (VANETs) has gained substantial interest of researchers from both academia and industry [1]. However, the advent of the technological paradigms of fog computing, edge computing, software defined networking (SDN), and network functions virtualization have led to considerable advancements for the wireless networking industry and transportation sector. This is augmented with pervasive usage of state-of-the-art sensors onboard the connected and autonomous vehicles (approx. 100 in number) which facilitates in the realization of a number of cooperative safety-critical vehicular applications, including but not limited to, vulnerable pedestrians collision mitigation, blind intersection warnings, forward collision warnings, emergency vehicle assistance, and vehicle lane changing assistance. These safety-critical applications typically require a low-latent infrastructure with a maximum tolerable delay of 100 ms [2].

Vehicular networking is a key technological paradigm which plays an indispensable role for the aggregation and dissemination of useful contextual information between the vehicles (Vehicle-to-Vehicle communication – V2V), between the infrastructure or network and vehicles (Vehicle-to-Infrastructure or Vehicle-to-Network communication – V2I / V2N), and between the vehicles and road pedestrians (Vehicle-to-Pedestrian communication – V2P). All of these strengthens the promising paradigm of Vehicle-to-Everything (V2X) communication, which is imperative for ensuring a highly secure and low-latent communication for diverse vehicular safety applications.

Nevertheless, the existing radio access technologies (RATs), i.e., DSRC, LTE-A, Wi-Fi, WiMAX, millimetre Wave, and the recently proposed Terahertz communication are not fully capable of *individually* catering to the performance requirements of diverse vehicular safety-critical applications, especially when their communication requirements are in conflict with one another. Hence, there has been a recent suggestion for equipping vehicles with *heterogeneous connectivity*, wherein each vehicle should be intelligent to opt for the most apposite RAT in order to guarantee a seamless, ubiquitous, and undifferentiated communication in an *Always Best Connected* mode. Heterogeneity, thus, is an important and timely research topic in VANETs and is in line with the essence of the 5G-PPP's *5G Vision* [3].

However, heterogeneity is not easy to tackle as the amalgamation of diverse RATs makes interconnection and interoperation an intractable task to handle, subsequently leading to fragmentation of network and inefficient resource utilization. To break such communication bottlenecks, the paradigm of SDN has been lately introduced for wireless networks. Accordingly, a number of researchers have envisaged architectural designs for the SDN-based vehicular networks along with highlighting their potential benefits and challenges. Yet, the notion of SDN-based heterogeneous vehicular networks (HetVNets) remains in its inception and demands considerable attention.

This paper, therefore, presents an ongoing research effort towards a novel SDN-based heterogeneous vehicular network for ensuring rapid network innovation via a highly re-configurable networking infrastructure as to meet the stringent performance requirements of diverse safety-critical vehicular applications.

II. Existing State-of-the-Art

In [1], the authors envisaged a hierarchical SDN architecture for vehicular networks and developed a communication protocol in order to address the loss of connection with the centralized SDN controller. In [2], an edge-up SDN-based design has been envisaged for vehicular networks and emphasis has been particularly placed on the latency control to support numerous applications for the next-generation of driving vehicles. In [3], a scalable and responsive SDN-enabled vehicular networking architecture, facilitated with mobile edge computing, has been suggested to minimize the data transmission time and for improving the quality-of-experience of users for latency-sensitive vehicular applications. In [4], a software defined collaborative edge computing framework has been envisaged for facilitating collaboration between the edge computing anchors to provide scalable and efficacious vehicular services. Moreover, potential vehicular edge computing cases, deployment technologies, and promising technology enablers have also been investigated.

In [5], the authors investigated the state-of-the-art research advances of SDN-based vehicular networks, and also outlined several requirements to ensure an efficacious network resource

978-1-5386-9151-9/19/$31.00 ©2019 IEEE

management. An architecture supporting the cohesion of SDN and named data networking has been highlighted in [6] to fetch the requisite content in vehicular networks. It assigns a name to the content (instead of the device, i.e., vehicle(s) or infrastructure), and a pull-based communication approach is accordingly utilized to retrieve the requisite content. Nevertheless, most of the said architectures did not take into account the notion of heterogeneity, governed the entire underlying network through a single centralized controller thereby resulting in an excessive load on the backhaul, and did not bring into consideration the unique VANET characteristics, i.e., high mobility of vehicles in the data plane, a large and highly distributed network at the edge, frequent changes in the network topology, and the need for extremely intelligent and low-latent handovers.

III. Towards Software Defined HetVNets

The promising paradigm of SDN was originally conceived and subsequently deployed for the orchestration and management of traditional data centres. Nevertheless, as-of-late, there has been a rapid shift of interest of academics and researchers to employ SDN for the wireless domains. SDN de-couples the control plane from the data plane, and the network intelligence is forwarded to a centralized software-based SDN controller for making simplified yet intelligent networking decisions. Reprogrammability, scalability, flexibility, elasticity, and agility are some of the SDN benefits which could enhance a network's overall management. It is also pertinent to mention that unlike conventional networks which are governed via a *single* point of network management (i.e., centralized controller), VANETs are highly dynamic and distributive in nature. Since the centralized controller plays a critical coordination role with highly dynamic vehicles and diverse RATs, its unresponsiveness may result in a *single point of network failure* and fatal accidents. Hence, localized intelligence should augment the centralized intelligence to ensure the reliability of SDN-based HetVNets. Vehicles, therefore, mostly relies on the localized intelligence and centralized intelligence is invoked once the local resources (i.e., both compute and storage) become inadequate.

Fig. 1 depicts a logical architecture of SDN-based HetVNet and is composed of a network infrastructure plane (data plane), control plane, and applications plane. The network infrastructure plane encompasses both the vehicles and vehicular users, roadside infrastructure, i.e., access points and/or base stations of diverse heterogeneous RATs, traffic lights, and pedestrians. V2X communication transpires at the data plane. The control plane is a software-based platform and governs the orchestration and management of networking functions virtualized from the network infrastructure plane. It collects and thus maintains the event-driven status of all SDN switches, creates and retains an up-to-date network topology, houses a frequency manager to ascertain the frequency of requisite vehicular applications and services, and a cache manager to guarantee an intelligent edge-based caching. Handover decision manager ensures that the vehicles remain seamlessly connected to the optimal RATs to meet their stringent performance requirements. Lastly, the applications plane offers a diverse range of vehicular applications and services imperative for devising a next-generation ubiquitous ITS platform.

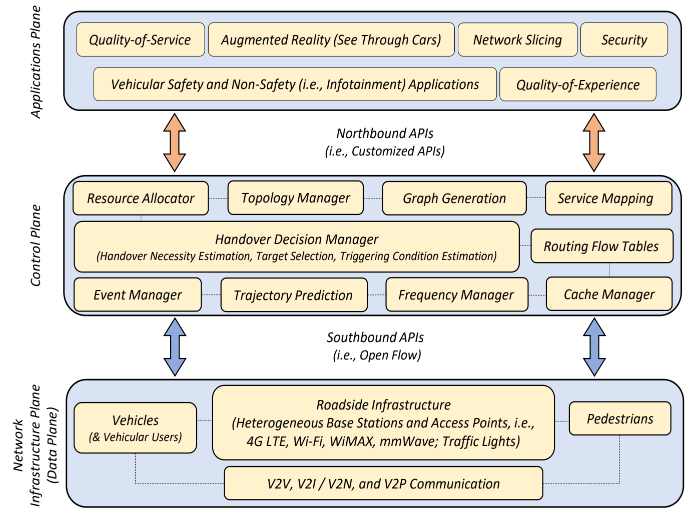

Fig. 1. A Logical Architecture of SDN-based HetVNet

IV. Acknowledgement

The author sincerely acknowledges the kind supervision of Quan Z. Sheng and Wei Emma Zhang for the research-at-hand.

V. Conclusion & Future Work

Managing of network resources in a dynamic and distributed vehicular networking environment is an arduous task to tackle. This becomes even further challenging when certain Quality-of-Service (QoS) requirements, i.e., higher bandwidth, extreme reliability, and low-latency for safety-critical vehicular applications have to be met. Although both SDN and heterogeneous networking have shown significant promise, nevertheless, they need to be integrated intelligently with VANETs for satisfying the QoS requirements of diverse vehicular safety applications. In the near future, the author also intends to suggest intelligent vertical handover algorithms, with intelligent edge-based computing, to manage the vehicular network resources efficiently.

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