Fog Computing as the Key for Seamless Connectivity Handover in Future Vehicular Networks

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ABSTRACT

With the emergence of highly automated and autonomous connected vehicles, rigorous requirements in terms of responsiveness, security and scalability become necessary to enable new services that improve efficiency and safety on the road. In future networks, vehicles need to frequently perform handover procedures while crossing various dense heterogeneous cells, which may cause an unacceptable network service degradation. In this concept paper, we propose a fog-aided architecture for seamless handover. Fog computing can fill the architectural gap between clients and clouds to manage short lived information and enable novel latency-critical applications at the edge of networks. Accordingly, the proposed architecture, along with its unified integration of virtually all devices (end-devices, gateways and servers) and all networks (ad hoc, access and core), supports Vehicle-to-Everything (V2X) distributed applications with crucial needs such as time-, safety- and security-critical network functions.

CCS CONCEPTS

• **Networks** → **Network protocol design**; **Network protocol design**; **Cross-layer protocols**;

KEYWORDS

Handover, Fog, V2X, SDN, NFV, delay-sensitive applications

1 INTRODUCTION

Through their journey, drivers require seamless continuity of applications such as voice call, data access, safety warnings, etc. However, this fundamental requirement is challenged by intermittent ad hoc links and short-lived connections to Base Stations (BS) caused by high mobility of connected vehicles and small size of future communication cells. Due to mobility, connected vehicles, also called User Equipment (UE), may frequently change their point of attachment (BSs and direct network neighbours), which requires a Horizontal Handover (HHO) process to hopefully ensure ongoing communication sessions. Modern vehicles usually are equipped with various network interfaces and should hop across available technologies such as 3GPP Long Term Evolution (LTE), LTE-V, Wi-Fi, IEEE802.11p, dedicated satellites, etc to overcome the limits of HHO or save communication costs, which requires appropriate Vertical Handover (VHO) mechanisms. Due to lack of appropriate holistic HO mechanisms cross technologies and cross layer in the literature, vehicular services currently might face unacceptable application degradations or even interruptions or high communication costs. Leveraging on Fog paradigm [1], this paper focuses on one key urgent need, i.e., to reliably and securely connect vehicles among each other either via terrestrial (Wifi, cellular, etc.) and/or satellite networks to enable the sharing of high context-rich, real-time, short-lived information. The Fog approach does not only ensure distributed low-latency communications, computation and data management needed in remote locations, but also security by reducing the volume of raw data shared with the cloud over the Internet.

In this position paper we first highlight the drawbacks and weakness of classical HO mechanisms, and then, we describe our view and approach to address them, using Fog Computing, Network Function Virtualization (NFV), and programmability features of Software Defined Networking (SDN).

2 REVIEW OF HANDOVER MANAGEMENT

Handover (HO) is a cross-layer concept. In the following, we review the state of the art in connectivity- and security-handover and identify the research gaps that we target to address through our proposed concepts.

2.1 Connectivity Handover

The HO process is a core element of cellular networks to support user mobility and it has been extensively addressed in literature. The classical HO process standardized by 3GPP is triggered by the UE, which detects that the difference between the Reference Signal Received Power (RSRP) of a neighbouring BS and the one of the serving BS is higher than a certain threshold. If this situation persists for a given amount of time (Time-To-Trigger, TTT), the HO is completed and the mobile node connects to the BS with

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the higher RSRP. With the 5G evolution of cellular networks, HO management is again receiving a high attention from academia and industry. In fact, the emerging network densification of small cells that aims to accommodate the higher traffic demand as well as the network slicing to provide for isolated mixed mode traffic, increases the HO frequency and the probability of service interruption, thus asking for new seamless HO techniques [2]. The static setting of the HO hysteresis and TTT values in the classical HO process is not effective in 5G Heterogeneous Networks (HetNets), which consist of traditional macro cells augmented by small/pico/femto/phantom cells, and may result in HO failure or HO oscillation [3]. Moreover, in highly mobile networks, such as vehicular networks, the UE has a short time to finalize the HO, due to the small size of cells. Hence, reactive HO mechanisms will result in degradation of connections and severer HO failure for UEs with high speed. Therefore, several studies proposed proactive context-aware HO mechanisms, which require cross-layer information [4–6]. Main elements of the context to ensure seamless HO are UE speed, UE trajectory, power profiles of the BSs and cells load. However, these techniques do not support VHO.

The limitations of classical cellular systems (4G, LTE) to sustain the bandwidth demand, and cope with increasing traffic load, together with the widespread availability of cellular and Wi-Fi networks, have triggered the definition of the IEEE802.21 standard for VHO, and in particular from wired IEEE802.3 network to wireless IEEE802.11, IEEE802.15, IEEE802.16, 3GPP and 3GPP2 networks through different HO mechanisms. However, this standard does not address the very low-latency needs for vehicles. The offloading techniques from cellular to Wi-Fi for smart phones have been successfully implemented, however not for latency-critical safety applications. Thus, handover mechanisms are needed to enable the end device to switch from 4G-LTE to Wi-Fi, without experiencing QoS degradation, due to reestablishment of TCP connection. To this aim, Multipath TCP (MPTCP) [7] was proposed and standardized at IETF, as a TCP extension that enables a single TCP connection to use multiple interfaces on the client and/or the server. MPTCP has been widely investigated in literature as a potential solution to address HO and mobility related service continuity issues [8] and several improvements have been proposed [9]. The proliferation of mobile devices with dual interfaces and the manufacturers interest to make their vehicles smarter and more competitive have created the ideal scenario for applying MPTCP in vehicular networks. A recent study [10] shows that MPTCP in Vehicle to Infrastructure (V2I) scenarios offers similar performance compared to TCP, while constantly handing over Wi-Fi and LTE networks. However, for the V2V scenario, MPTCP performance starts to suffer with the increase of vehicle speed. MTCP has been identified also as a suitable protocol for enabling integration of satellite and terrestrial networks [11]. Nowadays, satellite communications are seen as a key component of emerging 5G networks and connected vehicles. Only by integrating the two systems, it will be possible to enable new services, while meeting requirements such as high user data rates, and service continuity that cannot be achieved using either of the two technologies independently [11].

2.2 Security Handover

Delay sensitive applications not only require seamless connectivity, but also fast secure HO mechanisms for moving vehicles. To address different mobility scenarios, the 3GPP has defined key hierarchy and HO call flows for secure HO. Given that the authentication server is usually located far away from the UE, the chances of compromising session's keys are higher. Backward and forward key separation were introduced respectively to block destination BS from deriving past and future session keys from the whole chain of HO [12]. Since HetNets increase the heterogeneity for access systems resulting in more threats to the network security, 3GPP proposed HO authentication solutions between the E-UTRAN and the non-3GPP access networks, where a full access authentication procedure between a UE and the target access network is required before the HO happens [13]. Unfortunately, many of the available techniques for authentication handover are not suitable for the tight handover delay advocated by time-sensitive vehicular applications. Others do not consider the fact that connected vehicles are evolving in midst of HetNets that implement different authentication mechanisms. In addition, most of the existing security mechanisms for HHO rely on the transfer of a complex context, which induces significant delays to identify the target BS and to authenticate the server [14]. Recently, some studies have addressed the issues of authentication HO and privacy in 5G HetNets using SDN [15]. The basic approach consists in the transfer of a security context (physical layer attributes, location, moving speed and direction) using SDN-flow based forwarding to ensure faster and more robust authentication. The SDN intelligence ensures a more controlled HO with minimized redundant authentications across HetNets. Privacy preserving is achieved by data transmission over different paths. During its journey, a vehicle may move through several small cells and hence privacy is a paramount importance to ensure that the vehicle identity is not linked with the information of its owner. Traditional approaches use a pool of shorter-lived pseudonyms to preserve the privacy of users [16]. The problem is more challenging in 5G HetNets, where BSs may be untrusted or even compromised.

3 THE PROPOSED V2X ARCHITECTURE

According to the European 5GPPP initiative, which is one of the largest worldwide programmes designing future network generation *"The 5G technology includes a software-based system architecture, simplified authentication, support for shared infrastructure, multi-tenancy and multi-RAT (with seamless handover), support for terrestrial and/or satellite communication, robust security, privacy, and lawful interception capacity"* [17].

In this section, we present our proposal on leveraging on the 5G architecture, Fog computing along with the key 5G components, SDN and NFV, to achieve proactive, context-aware and secure handover mechanisms.

3.1 Fog Driven Architecture

With the increasing demand of time-sensitive distributed analytics processing, there is a paradigm switch in application development. The applications are moving away from being monolithic long-lived ones to applications that are built from loosely coupled components/microservices, which are sharable and mobile. Fog

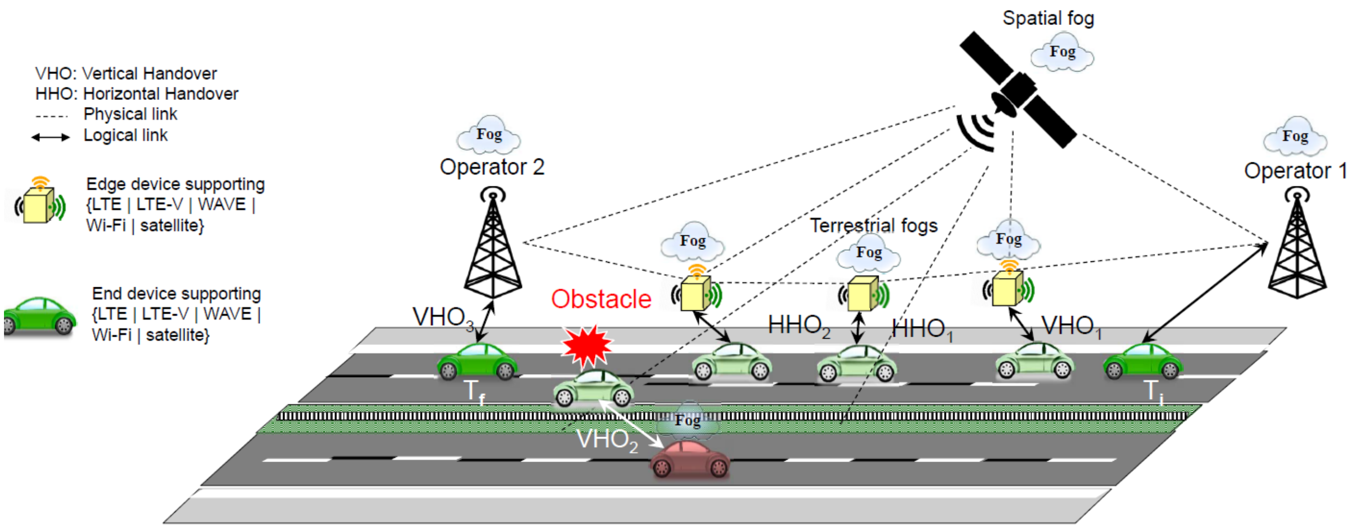

Figure 1: Example of network scenario supported by the V2X Fog-enabled Architecture: a vehicle on the highway losing some tire parts or transported goods.

computing, promoted by OpenFog Consortium, moves application logic and data as well as networking services near the end devices [18]. Hence, it is suitable for latency-sensitive distributed modern applications, such as safety applications for connected cooperative vehicles. Recently, the applicability of Fog in Vehicular Network Architectures, has been proposed in literature [6, 19, 20]. In particular, [6] proposes a cross layer and neighboring vehicle-aided fast HO in Fog-based architecture to deal with connectivity disruption, and achieve satisfactory user experience and online connections for vehicles.

Similarly to [21], in the proposed architecture we assume that connected vehicles are Fog devices with distributed intelligence. Vehicle mobility can be considered predictable to some extent: in fact, for a few minutes vehicles can show a predictable driving path at least for the time relevant for a short-lived application. Moreover, vehicles are relatively computing-resource rich. They do not have serious energy and computation constraints, and therefore may play the role of a moving Fogs. Furthermore, fixed edge devices that are equipped with a rich array of network interfaces (2G/3G/4G cellular, IEEE802.11a, b, p, Zigbee, etc.) and medium computation capabilities, may play the role of fixed Fogs. Vehicles may disclose their planned movement path to nearby fogs for a negotiated short time and in a privacy preserving way so that predictive HO will be possible. While moving, vehicles experience different HHO and VHO in the application lifetime (e.g. the green vehicle moving from time T_i, to time T_f in Fig.1).

Fig.1 shows the example of a delay-sensitive application scenario, supported by the proposed system architecture. A vehicle on the highway is losing some tire parts or transported goods. The obstacle detection application of the immediate successor vehicle behind should now process the sensor (e.g., camera or radar) data immediately, detect the obstacle and break autonomously. In addition, further affected successor vehicles behind should be informed that a full break (or an obstacle avoidance with an emergency lane change) is going to take place. Given the heterogeneity of the involved vehicles (multi-operator, multiradio-access-technology, heterogeneous computing/sensing/storage capabilities, autonomy degree, etc.), the support of the surrounding fog infrastructure is essential. An emergency call should take place with an information rich report, about the involved cars, the probable cause, etc. For long term statistics and forensics reports should be pushed with lower priority to the cloud. In this scenario, the HO is not just to ensure the connectivity of vehicles to each other and to the infrastructure, it is rather to successfully run the entire short-lived application of obstacle detection and warning.

3.2 SDN Enabled Architecture

To overcome the deficiencies in HO for time-sensitive applications, we propose to exploit, together with Fog Computing the benefits offered by network virtualization and programmability features of the SDN paradigm [22–26]. We envisage a SDN-enabled hierarchical architecture, depicted in Fig. 2. At the data plane, vehicles are enabled with satellite and terrestrial communication capabilities to support mixed-mode connectivity. The resources from satellite and terrestrial systems are logically federated together, to enable their easy control and allocation. SDN/NFV functions allow interchangeable provision between the two domains. Based on handover prediction, suitable proactive resource allocation and load balancing techniques can be implemented.

At the control plane, distributed controllers are implemented in Fog-enabled vehicles and BSs [21] to ensure fast and efficient HO and thus survival of ongoing sessions. The distributed controllers are orchestrated by a logically-centralized one. The application plane includes several vehicular services for drivers, autonomous cars and passengers. We assume that applications consist of several components that may be migrated to and run on different devices: end-devices (vehicles), mobile/fixed Fog devices and Cloud devices.

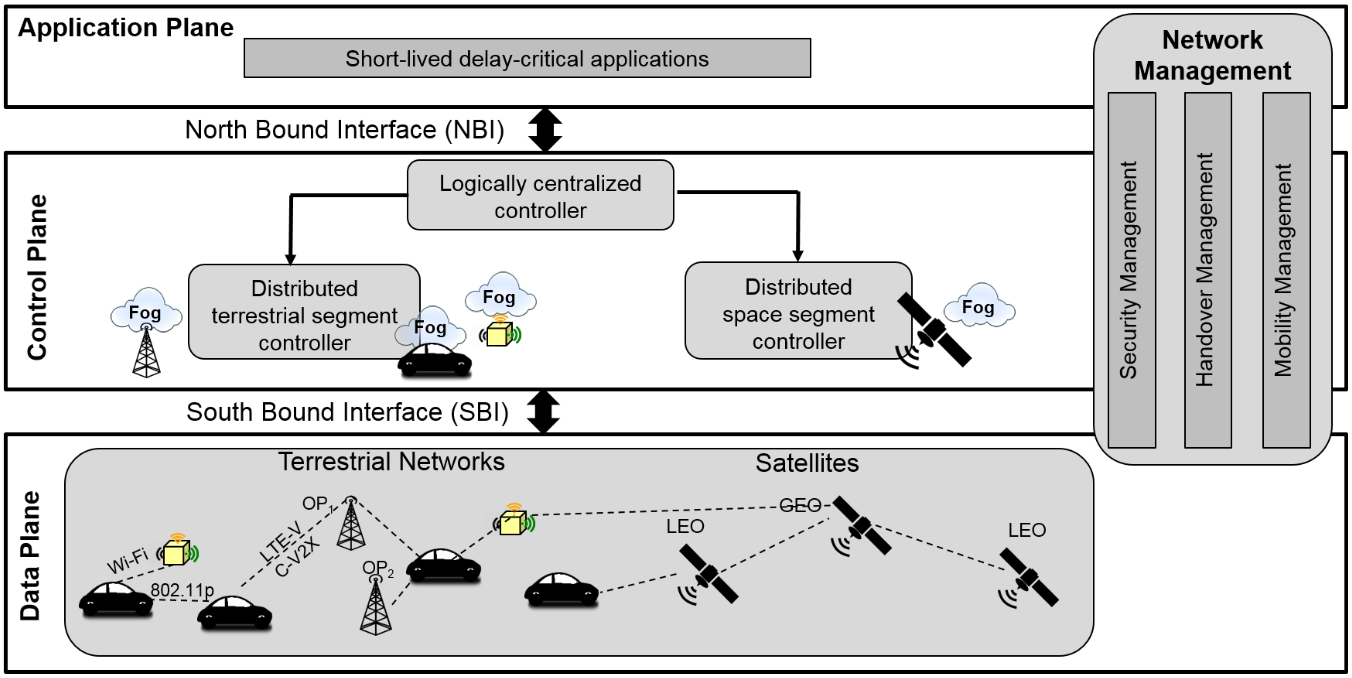

Figure 2: High level Fog-driven SDN-enabled V2X Architecture

For scalability and latency reasons, HO decision should be kept as localized as possible and orchestrated by the distributed controllers implemented in BSs, vehicles and satellites. Therefore, it is worth to implement the SDN parts of our solution in Fog-enabled devices/infrastructure that only respond to events taking place in their vicinity which ensures rapid, agile and secure reaction. To minimize the HO delay, we foreseen the adoption of a predictive approach, similar to [27], by securely sharing moving vehicle context attributes (ID, location, velocity, and expected path in the very near future) with selected BSs decided by the SDN control plane.

3.3 Security as a key Requirement

In the proposed V2X Fog and SDN driven architecture, Fog-enabled infrastructures have to authenticate incoming access requests. Widely distributed deployment of Fog devices will allow to deliver fast context-aware authentication check and consequently fulfill the requirement of low-latency applications [28]. At the same time, sharing the vehicle context attributes to enable fast HO may establish a link between shared information and the owner (moving vehicle). Therefore, we propose the provision of scalable privacy-preserving mechanisms to enable the planning of handovers with aggregated travel information without involving a trusted third party, which can become a network bottleneck given the frequent number of HO. Leveraging on distributed SDN controllers, privacy protection mechanisms can be provided to safeguard the privacy of involved players without causing computation burden and complexity to both the BS and the moving vehicle.

4 RESEARCH ROADMAP

Leveraging on the Fog-Enabled Architecture, we foresee the design of proactive cross-layer, cross-terrestrial-technology and cross-slices HO techniques. HO is obviously an important network control function. Following the softwarization trends of networks, we propose to develop a virtual network function (VNF) that is distributed across end/edge/core network devices and maps the network resources during the vehicle journey in the considered use cases, and schedules the best array of HHO and VHO in order to fulfill the application requirements without over- nor under-provisioning of resources. The novelty of our approach consists in designing a HO integrated framework with cross-* optimizations, i.e., a holistic HO that considers the HO recommendations on link, network, transport and application layers, as well as cross available access terrestrial technologies. To this end, we propose to develop the situation-awareness part of the VNF, i.e., predictive mobility management and context building such as prediction of network resource availability. To optimize the joint use of satellite and terrestrial resources, seamless handover techniques is proposed, starting from (and optimizing) those designed for terrestrial networks. Moreover, we need to go beyond state of art, and consider not only integration of satellite with LTE, but also with other terrestrial technologies, such as: LTE-V, IEEE802.11p, Wi-Fi, etc.

Next, the design and development of traffic prioritization schemes is required to support the provision of ultra-low-latency and critical services, where and as needed. These schemes should examine different network conditions and services requirements to map the application traffic to a few quality of experience classes.

A seamless handover is not only a fast handover but also a secure one that ensures the privacy of involved users. Sharing the vehicle context attributes to enable fast HO may establish a link between shared information and the owner (moving vehicle). Therefore, we propose to provide scalable privacy-preserving mechanisms to enable the planning of handovers with aggregated travel information without involving a trusted third party, which can become a network bottleneck given the frequent number of HO. Leveraging on distributed SDN controllers, we propose to provide privacy protection mechanisms to safeguard the privacy of involved players without causing computation burden and complexity to both the BS and the moving vehicle. A programmable privacy protection scheme will be set up by distributed SDN controllers to cope with the diversity of communications requirements, i.e., delay and scalability challenges. In addition, a NFV functionality at application layer with the support of Fog will guarantee that no matching can be established between the identity of the UE and its shared context information with Fog nodes.

It is also crucial to address the challenge of supporting fast secure authentication and re-authentication through avoiding the re-execution of the entire authentication method. Therefore, we need to design a SDN-enabled mechanism based on fogs that allows for optimistic/transitive authentication. We propose to exploit the predictability of handovers given the context information of vehicles to proactively plan the authentication handover. For less predictive scenarios there may be a need to establish transient/optimistic authentication on the fogs as part of the VNF.

5 CONCLUSION

Connected vehicles are transforming the way we travel by connecting people (drivers, pedestrians) with a constellation of devices (vehicles, traffic signals, sensors, wearables, smart phones, etc). Hence, the driver is a part of a long and heterogeneous chain that is larger than its vehicle. To ensure a full view of hazardous situations, this chain should provide pertinent and timely information to drivers during their journey. To this end, seamless handover between heterogeneous technologies is crucial to provide ubiquitous connectivity for delay-sensitive applications. In this concept paper, we articulated a crucial research gap, i.e., the need for a new holistic HO approach to support emerging vehicular applications in the 5G era that do not tolerate network disconnections and accordingly require zero-latency HO. Our research roadmap proposes to design novel secure and pro-active HO approaches that are (a) cross-layer, cross-slices, cross-operators etc, (b) aided by mobile, fixed or even orbiting fogs, and (c) inspired by the network softwarization trend.

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