LTE-based Automotive Mobile Virtual Network Operators

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Abstract— Connected cars offering services as driver assistance and navigation are already a part of our daily lives. The mobile connectivity in the car is often provided via an embedded SIM-card associated with a partner Mobile Network Operator (MNO). However, this solution ties the hands of Automotive Manufacturers (AM) due to high dependency on the partner MNO. In this paper, we focus on a promising way to overcome this dependency: becoming an automotive Mobile Virtual Network Operator (MVNO). In order to become an MVNO, the AM has to acquire a set of network components to gain control over the most important network functions. Based on in-depth LTE architecture analysis, we first identify the key LTE network functions and then propose respective automotive MVNO models. Moreover, we outline the current network technologies, e.g., Network Function Virtualization, that allow decoupling of the network functions from proprietary hardware. These technologies facilitate the MVNO implementation and operation as well as potentially reduce its cost.*

Index Terms—Mobile Virtual Network Operators, Intelligent Transportation Systems, connected car, LTE, LTE-A

1 Introduction

Offering network connectivity in vehicles, i.e., connected vehicles, has become the current trend of the automotive industry [1]. Today's vehicles are equipped with cellular connectivity to offer customers a wide variety of services, e.g., voice calling, video streaming as well as vehicle diagnostics or software updates. Connected vehicles contribute to increase in road safety that is also required by regulations in some countries. Examples of such regulatory initiatives on mandatory emergency reporting are eCall in Europe, or ERA-GLONASS in Russia. Technically, cellular connectivity currently is delivered in three ways [2]:

- Smartphone integrated solution, e.g., Ford "Applink" or Toyota "Entune". Such solutions rely on the user's smartphone connectivity and intelligence via an application.
- Tethering, e.g., Mercedes-Benz "Comand Online". The intelligence is implemented in the car and connectivity is provided by the smartphone.
- Embedded SIM, e.g., BMW "ConnectedDrive" or General Motors "OnStar", where both intelligence and connectivity are embedded in the car. This solution can be also combined with tethering.

The smartphone integrated and the tethering solutions are limited in their application range [2]. In general, mobile connection through user equipment, i.e., smartphone, is prone to human-caused errors, the phone can be stolen, forgotten or be out of battery or credit. Loss of connection limits not only the infotainment functions, but most importantly the safety ones. Moreover, remote services, such as vehicle software updates or remote vehicle ignition, are only possible with the embedded SIM solution. Embedded SIM solutions are even legally required for safety applications as in eCall. In case of embedded SIM, communication modem is a part of a car and cannot be removed or disabled by the user.

Unlike smartphone integrated and tethering solutions, embedded SIM cards are installed during the car production. It results in a lock-in to a Mobile Network Operator (MNO) or host-MNO, whose SIM cards were installed. The lock-in refers to the fact that in a current manufacturing and SIM embedding process it becomes almost impossible to change a host-MNO [3]. A feasible solution to the lock-in could be the GSM Association (GSMA) embedded SIM [3], it would allow changing the host-MNO without hardware change.

Even in the case, when changing a host-MNO is possible, network deployment, operation and management are fully determined by the host-MNO. Relying on a host-MNO hides from the AM the capability to identify failures and manage its own services. Hence, the AM cannot guarantee the required service quality [4] or tailor the network according to its needs. This implies that the quality of the services offered by the AM to its customers is tied with the network quality of the host-MNO.

Further, some AMs such as BMW and General Motors [2] have already invested in cellular technology by installing respective modems and embedding the SIMs. At the same time, the evolution and deployment strategies of cellular networks are solely defined by the MNOs. AMs are uncertain if the deployed MNO networks are able to satisfy the automotive requirements at reasonable cost; how long the networks will be operated; how and where the cover-

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*This paper refers to the state-of-the-art of 2014-2015.

age is going to be improved. The latter is one of the crucial automotive requirements: the MNOs tend to invest into densely populated areas [5], while cars need ubiquitous connectivity.

In our paper, we concentrate on overcoming these challenges through becoming an automotive MVNO. We list and analyze the options for an AM to achieve the independency from the host-MNO. We define gradual steps for an AM to become fully independent from an MNO. Each step is associated to one Mobile Virtual Network operator (MVNO) model. An AM becomes a virtual operator for a mobile network by acquiring and operating some network components or parts of the mobile network, except for the licensed spectrum Radio Access Network (RAN). We propose the groups of components based on their functions that can be operated "independently" from the rest of the network, for example mimicking the roaming case. These groups are defined based on detailed LTE specification analysis in application to the automotive case. Finally, we conceptually outline how the network functions can be decoupled from proprietary hardware components with Network Function Virtualization and Software Defined Networks. It has to be noted that we intentionally leave the legal aspects out of the scope, as they are country specific. Thus no generic statements can be made or worldwide scenarios derived. Such aspects include data ownership, privacy and roaming regulations.

The rest of the paper is organized as follows: in Section II, we introduce the state-of-the-art in the MVNO and automotive domains. Section III defines the main LTE entities and control functions that we then use for the automotive MVNO models introduction in Section IV. The paper is concluded by Section V, where the enabling concepts and technologies are briefly discussed.

2 STATE-OF-THE-ART

So far, the research on automotive topics and the Mobile Virtual Network Operators (MVNOs) have not been coupled. 3rd Generation Partnership Project (3GPP) defines an MVNO as an operator that offers mobile services, but does not own radio frequency [6]. This definition is adopted in our paper.

Previous research in the MVNO area has investigated MVNO classifications, e.g., according to network components owned [7] or business strategies [8]. Existing work has also tackled generic MVNO challenges, e.g., measuring MVNO performance depending on the host-MNO in real deployments [9]. In [4] authors identify ten MVNO problems and suggest a solution through acquiring certain network components. However, the common assumption is that all the MVNOs target the same market, i.e., Human-to-Human communications, and thus have the same requirements as existing MNOs. There is a view that MVNOs could enable Machine-to-Machine communications over cellular [10], with no in-depth discussion or application to the automotive case. In this paper, we tailor the MVNO strategies to the automotive requirements and motivation that are different to the conventional ones. AMs are international and have a unique set of basic applications, e.g., safety. Thus AMs are more sensitive to network performance controlled by the third party, i.e., MNO. Moreover, it is a long-term investment, where a clear migration plan is vital for market success.

The research in automotive communications focuses on choosing the appropriate technology for the manifold of automotive services with very different requirements under the constraint of very high mobility, e.g., [11]. Although the state-of-the-art vehicular technology is considered to be 802.11p, its scalability and QoS issues have leveraged LTE as a prospective technology for supporting vehicular communication [12]. A common assumption in automotive communication research is that the connectivity is ubiquitous and through a dedicated network, where the Quality of Service (QoS) is determined by the AMs. This assumption cannot be generalized to all AM and MNO agreements.

In our previous work [1] we have taken a first step towards identifying the automotive requirements and the challenges of different MVNO solutions. The current work provides a deeper insight into the technological aspects of the LTE-based automotive MVNOs as a promising cellular technology [2].

3 LTE FUNCTIONS FOR AUTOMOTIVE MVNOS

Cellular MNOs possess a complex, mostly hardware-specific network architecture that evolved and expanded over time and with technology development. Thus it combines several generations: 2G, 3G and 4G. Market newcomers, as automotive MVNOs, can start directly with 4G. In this section, we introduce the most relevant for automotive MVNO LTE network functions.

LTE access network is called Evolved Universal Terrestrial RAN (E-UTRAN, referred here to as RAN). It operates in the licensed spectrum and consists of only evolved Nodes B (eNBs) (3GPP TS 36.300). eNBs are intelligent nodes that are responsible for many functions, e.g., radio resource management.

Evolved Packet Core (EPC) is a fully packet switched core network that supports interoperability with the legacy generations, e.g., 3G, as well as with the non-3GPP networks, e.g., Wi-Fi or WiMAX. EPC with RAN architecture is shown in Figure 1 (3GPP TS 23.401). We introduce the elements based on the independence from the rest of the network.

Home Subscriber Server (HSS) is a central database for the user-related information, which takes part in most of the fundamental network procedures such as mobility management, user security support and user service provisioning (3GPP TS 23.401). Owning an HSS brings the

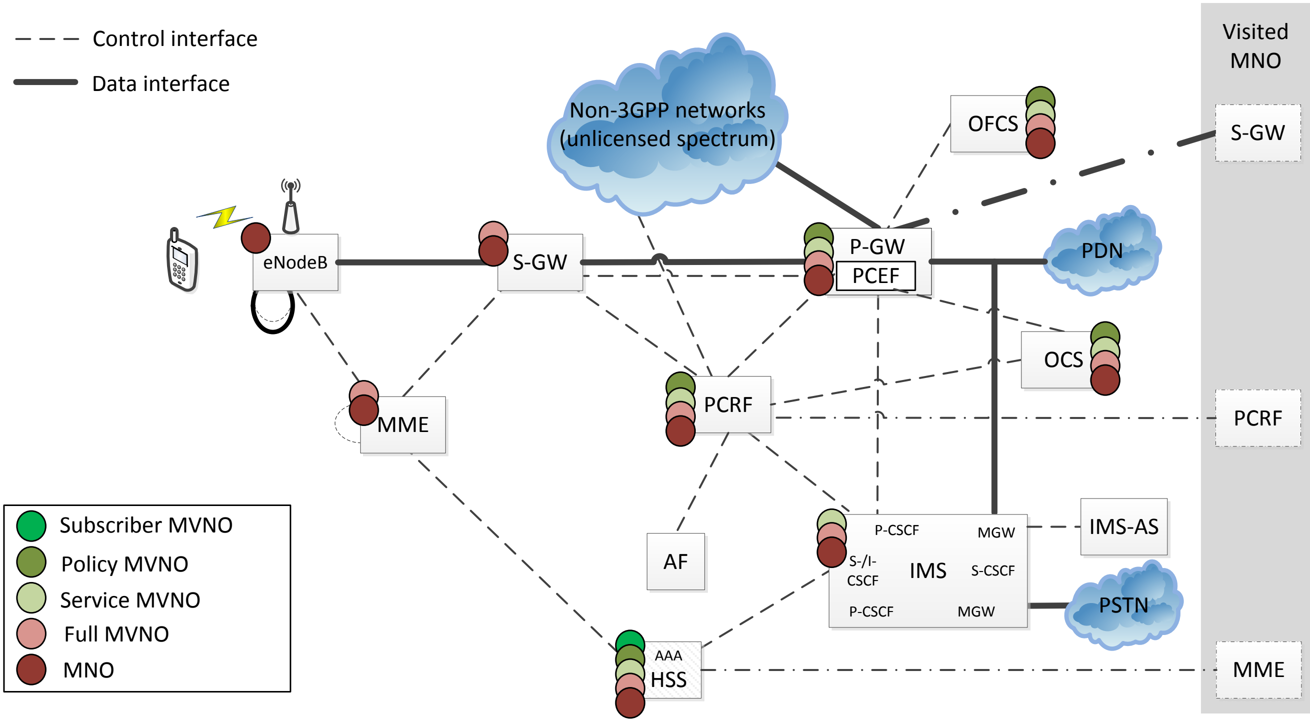

Figure 1 Technology Map: Evolved Packet Core and its LTE Radio Access Network. MVNO notation is explained in Section IV.

flexibility to access the user data independently from the host-MNO and to dynamically tailor the subscriptions, i.e., change the subscriptions as needed.

Packet Data Network Gateway (P-GW) provides connectivity from the user to external packet data networks. P-GW allows per-user packet filtering, e.g., deep packet inspection; IP address allocation and packet screening. Policy and Charging Enforcement Function (PCEF) is a part of the P-GW. It assists charging and enforces the policies that were determined by the Policy and Charging Rule Function. Policy and Charging Rule Function (PCRF) makes policy control decisions regarding the service data flow detection, gating, Quality of Service (QoS) and provides them to the PCEF (3GPP TS 23.203). Offline Charging System (OFCS) and/ or Online Charging System (OCS) perform charging (3GPP TS 23.203).

P-GW and PCRF allow dynamic traffic control, QoS provisioning, and traffic shaping (3GPP TS 23.401). Figure 2, based on [14], 3GPP TS 23.401, 3GPP TS 23.203 and 3GPP TS 36.300, shows a simplified example of QoS enforcement for the uplink. In this example, there is one default bearer (ID=1) with no Guaranteed Bit Rate (non-GBR), and two associated dedicated bearers to the default bearer, non-GBR with an ID = 2 and GBR with ID = 3.

The uplink initial traffic control and policy enforcements are done at the User Equipment (UE), i.e., car modem, on which AM has direct influence. At the UE and the other network components, filtering parameters are defined by the PCRF and rate policing by the HSS, i.e., user subscription. The only point, where other network functions could potentially influence the policy assigned by the PCRF, is an eNB during scheduling. Scheduling at the eNB is not specified by the 3GPP and left for the implementation choices of the MNOs. Although theoretically QoS aware scheduling is possible, in practice that could introduce extra complexity and processing delay at the eNB, which is not desired by any operator. The other components needed for uplink QoS enforcement are owned by the Policy MVNO.

Figure 3, based on the same references, depicts the same simplified example but for downlink. In the downlink, the PCEF in the P-GW does the initial policy enforcement, where the policies are fetched from the PCRF. The eNB in this case is responsible for the rate policing for the non-GBR bearers, the rates for which are defined by user subscription and stored in the HSS.

Policy control together with Online Charging System (OCS) allow controlling user services in real-time, e.g., the service is not completely blocked, however its data connection speed is throttled (3GPP 23.203). As shown in Figure 1, the P-GW supports interoperability with the non-3GPP networks, e.g., Wi-Fi (3GPP TS 23.401). Thus it allows network coverage extensions in the unlicensed spectrum (3GPP TS 23.261).

Thus, in order to control uplink and downlink traffic policing, it is enough to have HSS, P-GW and PCRF. For accurate charging, OCS and Offline Charging System (OFCS) rely on the traffic statistics from P-GW. So for charging it is important either to have direct access to P-GW information or to own a P-GW.

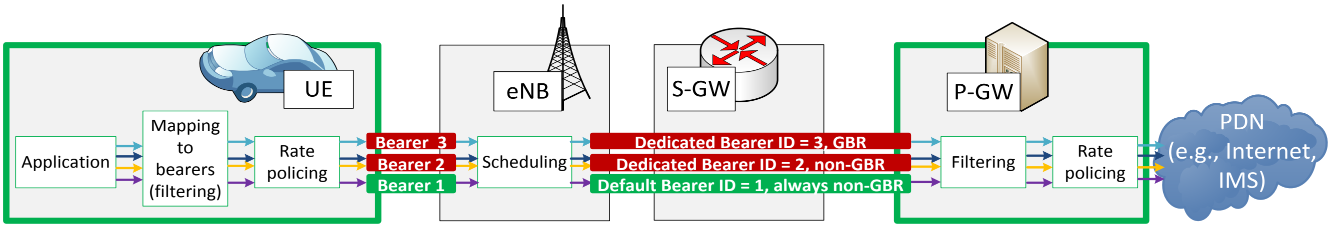

Figure 3 Simplified example of LTE uplink QoS enforcement. The components with the green frame enforce the policies and are controlled by the Policy MVNO. MVNO notation is explained in Section IV.

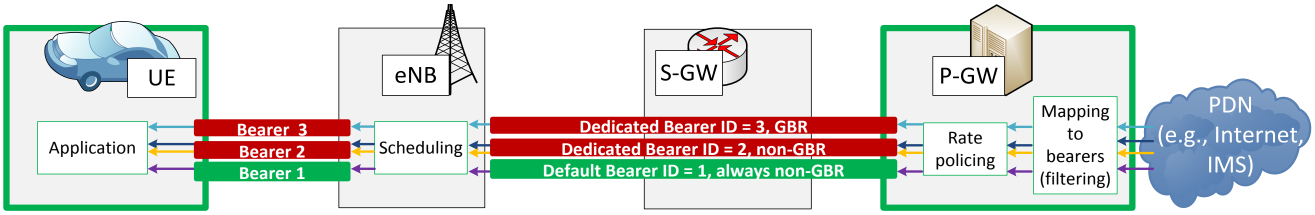

Figure 2 Simplified example of LTE downlink QoS enforcement. The components with the green frame enforce the policies and are controlled by the Policy MVNO. MVNO notation is explained in Section IV.

Mobility Management Entity (MME) is the key signaling control node dealing with, e.g., user paging, bearer activation and deactivation process. Serving Gateway (S-GW) is responsible for routing and forwarding data packets, as well as for taking care of handovers within LTE and between LTE and other 3GPP technologies. Owning MME and S-GW brings benefits only if the rest of the EPC is owned and there is LTE RAN to control.

Figure 1 also shows the roaming case, where the network components on the grey background represent a visited-MNO. In the home network, the network components responsible for the roaming are HSS for subscription related information as well as the P-GW and PCRF for correct policing. Combination of HSS, P-GW and PCRF is technically capable of setting up its own roaming agreements.

IP Multimedia Subsystem (IMS) can be seen as a part of the EPC, as in Figure 1, or as a separate packet network with the same functions. In both cases, it is responsible for service management and provisioning, as well as for compatibility with circuit switched services (3GPP TS 23.228).

4 Migration towards Independency: Evolution of Automotive MVNO Models

First, we discuss the current status of the Automotive Manufacturers (AMs) in the communication market. Then we introduce and analyze migration options towards full independency from the host-MNO, i.e., becoming an MNO itself. Finally, the proposed models are qualitatively evaluated on an individual basis with an emphasis on their potential gains and problems.

The current dominating business model for AMs is MVNO without owning any network components or a Reseller. The Reseller is a provider, who reuses spare resources of the host-MNO and differentiates its offers mainly through marketing and targeted audience [8]. The Reseller is fully dependent on the host-MNO because it neither owns (operates) any network components, nor provides own services. Thus AMs often evolve to an Enhanced Service Provider owning value added service platforms [7], [8].

These two models are shown at the bottom of Figure 4, which illustrates a qualitative evolution from an automotive MVNO to an MNO. The x-axis indicates the costs that are inherent to the models. These costs are not in scale. The y-axis shows a relative degree of dependency on the MNO with the extreme cases: Reseller is fully dependent on the host-MNO, whereas an MNO is totally independent. The top row shows the network components that are owned by each model, which are also marked in the technology map in Figure 1. Every presented model is an evolution step or an upgrade to the previous one gaining a higher degree of independence from an MNO, without losing the advantages of the previous models.

The rest of the section is dedicated to the individual model discussion with an emphasis on the gains that are acquired with the network components. The Subscriber and Service MVNO (Service MVNO referred in [13] as Full MVNO) were first introduced in [13] and therefore are only briefly discussed here.

Subscriber MVNO

The first proposed automotive MVNO model, as shown in Figure 4, is the Subscriber MVNO [13]. Subscriber MVNO owns an HSS with an in-built Authentication, Authorization and Accounting server. With the HSS the Subscriber MVNO can achieve more privacy since it manages and stores the user subscription in its domain.

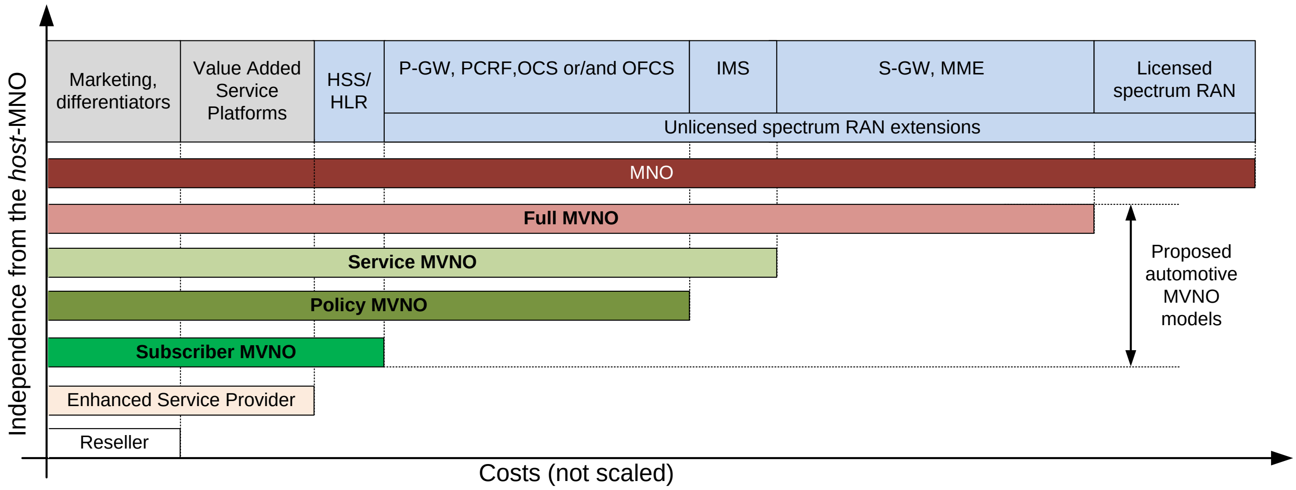

Figure 4 Business models evolution in relation to the owned network components, the costs involved and independency from a host-MNO. The mapping of the business models to the network components is shown in Figure 1.

Hence, the degree of independence from the host-MNO is substantially increased compared to the Enhanced Service Provider.

The drawback of the Subscriber MVNO, is its dependency on the host-MNO in all the other functions that are provided by the network components other than HSS, e.g., data traffic shaping and provisioning of QoS guarantees. Furthermore, roaming agreements in this case still depend on the host-MNO.

Policy MVNO

Policy MVNO owns a P-GW, PCRF, OCS and/or OFCS as well as an HSS. Hence, it is possible to establish own roaming agreements as discussed in Section III. The reason to gain the P-GW, PCRF and charging systems together is the information interdependencies between the network components. For example, P-GW cannot define the policies on its own; it needs the PCRF, which needs the information from both: HSS for user subscription information and OCS for service quota. The OCS in its turn needs the traffic information gathered at P-GW for correct charging and PCRF needs the P-GW for policy enforcement.

Since the Policy MVNO owns all the components that are necessary for roaming, it can "roam" through a number of visited-MNOs, e.g., to achieve the best possible coverage for its needs. Thus there is no single host-MNO, but a number of visited-MNOs to fulfill the AMs' goals. Moreover, if the coverage of visited-MNOs is not enough, Policy MVNO can extend or improve the coverage through unlicensed spectrum RAN, e.g., Wi-Fi or DSRC.

Policy MVNO gains substantial independency compared to the Subscriber MVNO, it still has a number of limitations. The first limitation is the coverage in the licensed spectrum RAN that is totally defined by the visited-MNO needs. Although the unlicensed spectrum is there for use, it suffers under low QoS guaranties and high interference due to many uncontrolled users. This is why for the required performance of critical services in terms of reliability and delay, the RAN in licensed spectrum is needed. The second limitation is that Voice over LTE (VoLTE) and other services that are provided through IMS depend on the party, e.g., visited-MNO, that owns the IMS.

Service MVNO

The limitation in services of the Policy MVNO is addressed by the Service MVNO by acquiring an IMS additionally to the network components owned by the Policy MVNO. Thus the Service MVNO possess all the benefits of the Policy MVNO and is able to manage and provide advanced services, e.g., Voice over IMS (VoIMS), as well as the legacy ones, e.g., compatibility with Circuit Switched (CS) calls (3GPP TS 23.228). As the IMS is access agnostic it would provide Service MVNO independence from the underlying network and, thus, allowing a broader choice of the visited-MNOs. Gaining an IMS without the rest of the components could be beneficial with other requirements, e.g., for becoming an advanced service provider.

This service improvement is advantageous for the AMs as it offers the possibility to control a wide range of conventional and individual services independently from the access technology. It contributes to customer satisfaction and their willingness to pay. According to an Alcatel–Lucent survey over 2000 consumers, 22% of consumers would be willing to pay $30–65 per month for value-added connectivity services in a car[1], i.e., for infotainment. It corresponds to the current trends in connected cars, most of the services implemented at the moment are infotainment: from navigation to music streaming. However, this advantage comes at a cost of the IMS as well as higher complexity, maintenance, operation and control (3GPP TS 23.228).

Full MVNO: towards full independency and becoming an automotive MNO

The Full MVNO possesses a full EPC together with IMS. Full MVNO shall be seen as a transition towards the au-

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tomotive MNO. The benefits of owning an S-GW and an MME can be limited without owning a licensed spectrum RAN. As soon as the AM acquires the RAN in licensed spectrum it becomes an automotive MNO according to our definition. The usual RAN deployment strategy for conventional MNOs is based on the population density: more connectivity, where most of the customers are [5]. However, for the automotive case the population density is not the only parameter to take into account, e.g., roadmaps or ubiquitous availability of safety services. Hence, one of the crucial requirements for the automotive connectivity is ubiquitous coverage. With an entire packet core and a spectrum license automotive MNO can first cover the missing crucial areas. Later the automotive MNO can specify the coverage expansion strategy based on its own set of requirements and thus getting the most of independency of an MNO(s).

Full MVNO and automotive MNO possess the highest degree of independency from the visited-MNO/ s: they control the entire core network. In the case of automotive MNO there is also the freedom for coverage expansion in the areas, where the conventional MNOs are not interested, e.g., rural. This freedom comes at high costs of all the core network components, i.e., MME, S- and P-GWs, PCRF, HSS; charging system, i.e., OCS or OFCS; IMS as well as the eNBs and licensing. The high complexity of the system means complex operation and maintenance demanding qualified work force. This task can be very challenging, as AMs have limited or no experience in telecom operation.

5 MVNO Technology Drivers: Recent Networking Concepts

There are several recent networking initiatives and concepts that can act as fundamental drivers for AMs to enter the telecom market and become an MVNO. An ETSI initiative in 2012 [15], namely, Network Functions Virtualization (NFV), replaces hardware-integrated network functions, such as MME, HSS, S-GW, P-GW in the mobile network case, with software functions that can be hosted on commodity IT hardware. NFV complemented with cloud computing, i.e., data centers, can be considered as a step towards simplifying the acquisition of network functions and as a main driver for the MVNO use-case. Services are expected to be deployed more rapidly with the support of highly scalable network operation. Software network functions also add a lot of flexibility for AMs to change their MVNO model/ role. Finally, with this migration from hardware-integrated solutions to software, NFV is expected to lower both: network components cost (CapEx) and operational cost (OpEx).

As for the interconnecting network between the network functions, Network Virtualization (NV) can be seen as a viable solution to achieve further Total Cost of Ownership (TCO) reduction and flexibility support [16]. Through NV, the physical network infrastructure can be shared among multiple market players, including MVNOs. Each MVNO can acquire and operate a virtual network, which reduces the expenditures of owning a physical network. Virtual networks offer MVNOs the flexibility to restructure and change their virtual topologies more dynamically, through migration of virtual links or nodes. Additionally, virtual networks can be extensible, through requesting additional virtual resources, in contrast to physically adding a network node or link that requires renting a location or trenching.

A further enabling concept, that has been widely adopted, is Software Defined Networking (SDN). SDN decouples network functions into data and control planes with a programmable interface in-between. SDN can be seen as an enabler for more flexible and programmable network operation [15]. Off-the shelf SDN switches could be used to achieve on-demand traffic steering to the different MVNO network functions. SDN can be used as well to split a network function into data and control parts. Through SDN, automotive MVNOs can achieve a more tailored and fine-granular operation of their acquired network that can result in a better and robust services, e.g., for safety applications. Programmable network configuration can also contribute to operational cost savings.

Conclusion and Outlook

Competition and fast evolution of services and user expectations attract traditionally non-telecom industries like Automotive Manufacturers (AMs), to enter the telecom sector. Currently AMs mostly rely on *host*-Mobile Network Operator (MNO), which results in no access or control over the underlying communication infrastructure. This raises a number of connectivity issues as limited subscription management or policing, while being not able to easily change the *host*-MNO. This lack of guarantees of meeting the required network performance is the main challenge that we have identified. After an analysis of the key LTE network functions, we propose a migration strategy for an AM from full dependency on the *host*-MNO to full independency. The migration can be made through different stages, the so-called Mobile Virtual Network Operator (MVNO) models. We introduce, describe and analyze four MVNO models that offer a gradual independency increase. For example, to gain the flexibility to access the user data independently from the *host*-MNO and dynamically tailor the subscriptions, we propose acquiring the Home Subscriber Server (HSS) and thus becoming a *Subscriber* MVNO. There exist technologies that allow operating network functions in software (e.g., running in a data center). One example is Network Function Virtualisation (NFV), which allows running software functions on commodity hardware, instead of on specific, complex and costly hardware. These technologies will pave the way to AM to become MVNO and even MNO.

For future work, there are several open issues that could to be addressed. There are legislative issues that can be investigated, e.g., data ownership, roaming agreements, or MVNO status in general. Moreover, an interoperation strategy between the automotive MVNO/ MNO and its partners can be further defined in terms of shared interfaces, information and security. Deeper analysis of the proposed automotive MVNO models can be a further step towards bringing the AMs to the independency from the MNOs.

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