5G for Vehicular Communications

Syed Adeel Ali Shah, Ejaz Ahmed, Muhammad Imran, and Sherali Zeadally

Abstract

5G is ongoing, and it is an emerging platform that not only aims to augment existing but also introduce a plethora of novel applications that require ultra-reliable low-latency communication. It is a new radio access technology that provides building blocks to retrofit existing platforms (e.g., 2G, 3G, 4G, and WiFi) for greater coverage, accessibility, and higher network density with respect to cells and devices. It implies that 5G aims to satisfy a diverse set of communication requirements of the various stakeholders. Among the stakeholders, vehicles, in particular, will benefit from 5G at both the system and application levels. The authors present a tutorial perspective on vehicular communications using the building blocks provided by 5G. First, we identify and describe key requirements of emerging vehicular communications and assess existing standards to determine their limitations. Then we provide a glimpse of the adopted 5G architecture and identify some of its promising salient features for vehicular communications. Finally, key 5G building blocks (i.e., proximity services, mobile edge computing and network slicing) are explored in the context of vehicular communications, and associated design challenges are highlighted.

Introduction

Vehicles will be an integral part of the modern era of communications that promises to provide ubiquitous connectivity, and ultra-reliable and low-latency transmissions. While the idea seems far-fetched, efforts are already underway to achieve this goal using the proposed fifth generation (5G) communication architecture [1]. 5G is not only a new access technology but also a user-centric network concept that aims to address the application requirements of all the stakeholders in the connected world. In practice, because of the existence of such a range of access technologies and numerous use cases in the connected digital world today, it is not possible to design a unifying technology that addresses the diverse set of communication requirements. Therefore, 5G does not aim to change the existing communications architecture (i.e., LTE) but rather provides a unifying platform that leverages all the existing and envisioned techniques that offer a diverse set of services to the customers. From a business perspective, such a strategy would also mean that the return on investments made in the current infrastructure (e.g., LTE) will be high for many years to come.

5G aims to support new air interfaces along with some new access techniques over the newly assigned spectrum. More importantly, it will be built upon the current wireless technologies including LTE, high-speed packet access, Global System for Mobile Communications, WiFi, and so on. However, to provide a platform for the existing technologies to coexist, it is important to specify the basic building blocks of 5G. For instance, some crucial building blocks for 5G include but are not limited to the technology to discover and provide services using proximity information, network slicing techniques, software defined networks (SDNs), mobile edge computing (MEC), and millimeter-wave communications (i.e., in the 28 GHz, 38 GHz, 60 GHz, 71–76 GHz, and 81–86 GHz band) [2].

The main concerns in the present vehicular communication standards (i.e., IEEE 802.11p) [3] include the lack of spectrum, low latency, and highly reliable transmission of periodic communications. The existing standard has shown poor scalability and lacks guaranteed service delivery in large-scale network deployments. While some studies have already been undertaken on LTE-based vehicular communications, the promises being made by the successor of LTE (i.e., 5G) motivate further research on 5G-enabled vehicular communications. Current efforts include the collection of diverse application requirements and some initial standard specifications for the deployment of 5G until 2020. To the best of our knowledge, this is the first tutorial perspective on 5G for vehicular communications.

A study in [4] focuses on the vehicular standardization efforts and subsequently analyzes the enabling features of LTE for vehicular networks. Another study in [5] discusses the key requirements for SDNs to work with vehicular networks. This study aims to give an impetus to the ongoing 5G efforts and its understanding toward vehicular communications. The distinguishing feature of this article is to present the perspective of 5G-enabled vehicular communications using some of the key 5G building blocks. First, we assess the existing IEEE 802.11p standard for vehicular communications. Second, we identify the 4G LTE capabilities that are most promising for adoption in 5G. Finally, we present the most relevant building blocks of 5G that are applicable to vehicular communications followed by a discussion of some of the future research challenges that still need to be addressed to enable 5G vehicular communications.

The authors present a tutorial perspective on vehicular communications using the building blocks provided by 5G. They identify and describe key requirements of emerging vehicular communications and assess existing standards to determine their limitations. They also provide a glimpse of the adopted 5G architecture and identify some of its promising salient features for vehicular communications.

Syed Adeel Ali Shah is with the University of Engineering & Technology Peshawar; Ejaz Ahmed is with the University of Malaya; Muhammad Imran is with King Saud University; Sherali Zeadally is with the University of Kentucky.

Digital Object Identifier: 10.1109/MCOM.2018.1700467

0163-6804/18/$25.00

A major portion of the dedicated spectrum in IEEE 802.11p is utilized by periodic beacons, causing it to quickly reach its capacity, and the spectrum scales poorly during high communication activity. To cope with congestion, the standard must incorporate techniques to control congestion based on parameters such as vehicular density, channel states, and bit error rates.

System requirements	Description	Status of IEEE 802.11p
Minimizing communication load	Amount of information sent for achieving a desired level of neighbor awareness	Inadequate provisions in IEEE 802.11p for minimizing communication load due to the requirements of high message frequency transmission on a shared and scarce spectrum
Support for diverse applications	Ability to satisfy diverse vehicular applications including safety, non-safety, and infotainment	Not fully compliant for application due to the inherent requirement of infrastructure deployment
Congestion control mechanisms	Mechanisms to control the state of high spectrum utilization	Lack of conclusive adaptive beaconing approaches for congestion control
Fairness in accessing resources	Fairness in transmission power, message frequency, and fair access of resources across the network	Fairness cannot be guaranteed due to the shared channel access mechanisms
Reliability	Guaranteed transmissions of high-priority safety messages	In a shared channel access scenario, prioritized delivery mechanisms still introduce erroneous transmissions

Table 1. Status of system requirements for IEEE 802.11p-based vehicular communications .

Assessing the IEEE Vehicular Communications Standard (IEEE 802.11p)

Several vehicular communication system requirements are pertinent to safety and non-safety applications. These requirements include:

- Minimizing communication load
- Support for diverse applications
- Congestion control mechanisms
- Fairness in accessing resources
- Reliability

Here, we discuss these system requirements with reference to IEEE 802.11p. Table 1 summarizes these requirements and their status.

Minimizing Communication Load

Vehicular safety applications rely on status information (i.e., beacons) that must be periodically broadcast by each vehicle in the network, which leads to high communication load. It can also be considered as the additional workload incurred to achieve a specific objective function (i.e., acquiring a high level of neighbor awareness). High communication load can affect the performance of vehicular safety applications because of higher erroneous transmissions that increase latency in acquiring awareness. While adaptive beaconing approaches could be used to reduce load and improve latencies [6], the current status of IEEE 802.11p is inadequate in minimizing the communication load. This is mainly because of the high message frequency requirements of safety applications in a scarce and shared wireless spectrum.

Support for Diverse Applications

Besides safety applications, vehicular networks have the capability to host non-safety applications such as traffic information systems (TISs) and infotainment applications such as peer-to-peer (P2P) gaming, Internet content sharing, and IPTV. These applications have different requirements compared to safety applications. For instance, periodic beacon dissemination for safety applications is delay-sensitive, while non-safety applications (e.g., TISs) can tolerate a certain level of delay. Infotainment applications, on the other hand, require service guarantees and improved user experience. In the IEEE 802.11p standard, supporting a truly diverse set of applications requires infrastructure-based communications (i.e., using roadside units, RSUs) to cope with the effect of intermittent connectivity that is vital for non-safety and infotainment applications. However, widespread deployment of RSUs for vehicular networks may not be practical. Therefore, IEEE 802.11p does not fully meet the application diversity requirements of vehicular communications.

Congestion Control Mechanisms

A major portion of the dedicated spectrum in IEEE 802.11p is utilized by periodic beacons, causing it to quickly reach its capacity, and the spectrum scales poorly during high communication activity. To cope with congestion, the standard must incorporate techniques to control congestion based on parameters such as vehicular density, channel states, and bit error rates. These techniques can be based on an open-loop (i.e., requiring feedback from the neighbors) or a closed-loop (i.e, requiring only local rules) strategy. Ideally, the channel congestion should be minimized in order to increase the probability of transmission for spontaneous, event-driven messages. The current status of IEEE 802.11p relies on congestion control techniques such as transmit power, message frequency, and contention window adaptations. However, none of these techniques are proven to be sufficient for large-scale network deployments.

Fairness in Accessing Resources

The variations in vehicular mobility and communication patterns are spatio-temporal. In particular, the vehicles within a transmission range have distinct views of the current topology and the network state. Moreover, depending on the traffic situation, vehicles may have different requirements for communication. This calls for fairness in all aspects of vehicular communications, including channel access, message transmission frequency and transmission power. In other words, fairness ensures that transmissions from one vehicle do not have repercussions on transmissions made by neighboring vehicles. One fairness approach is to enable coordination among vehicles on their views of the topology and network states. For instance, the number of neighbors, channel busy ratio, and message prioritization can be shared by vehicles. However, IEEE 802.11p is predominantly based on shared channel access in which fairness in resource sharing cannot be guaranteed.

Reliability

A vital requirement of safety applications is the timely and reliable delivery of high-priority beacons. It is worth noting that, due to the limited validity of the periodic beacons, there are no acknowledgment mechanisms for erroneous transmissions. Moreover, a received message is considered outdated (based on a timer within each beacon) by the destination soon after it is delivered. Likewise, the message is dropped at the source if it is not transmitted (due to high contention in high-density scenarios) within due time.

Therefore, to improve reliability and time-constrained delivery of beacons (especially event-driven), some priority mechanism is needed. This is to ensure that high-priority messages do not compete with the periodic beacons for channel access. However, as mentioned before, for large-scale network deployments, erroneous transmissions can still occur due to limited available spectrum, which makes the IEEE 802.11p unreliable for vehicular communications.

The lack of provisions for satisfying the key system requirements of vehicular communications motivates the interest in using 5G for vehicular communications [7]. While the exact 5G standardization of procedures to satisfy the system requirements posed by vehicular communications is difficult to determine, a few 5G-enabled communication perspectives can be anticipated as a baseline for satisfying these requirements.

Technological Trends and Takeaways

This section presents a brief overview on LTE as the key wireless technology in 5G. We then highlight some salient aspects of LTE that are crucial in 5G vehicular communications.

LTE

4G LTE has become widely accepted as the technology of choice by the wireless industry. Figure 1 depicts three main LTE architectural components, that is, user equipment (UE), the evolved universal terrestrial radio access network (E-UTRAN), and the Evolved Packet Core (EPC). The interfaces between different parts of the system are denoted by Uu (between UE and E-UTRAN), S1 (between E-UTRAN and EPC), and serving gateway interface (SGi) (between EPC and packet data network, PDN). The data plane consists of UE and E-UTRAN. The former comprises mobile termination (handles all the communication functions), terminal equipment (terminates the data streams), and universal integrated circuit card (i.e., SIM card). The latter has just one component, called evolved Node B (eNB), and handles the

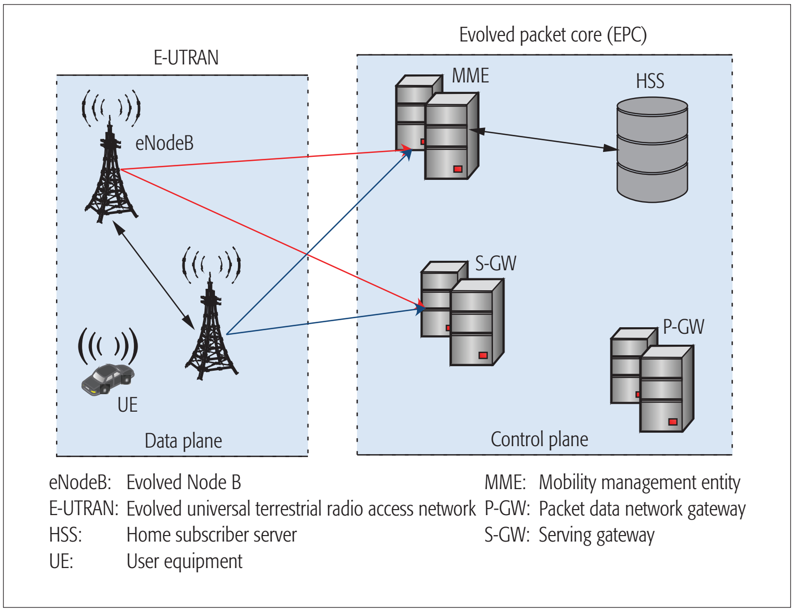

Figure 1. Long Term Evolution architecture for adoption in 5G.

radio communications between the mobile devices and the EPC. Each eNB is a base station that controls the mobile devices in one or more cells. The forwarding, routing, and control decisions are made by the control plane of LTE, which are subsequently executed by the data plane. The control plane mainly consists of EPC, which also communicates with PDNs such as the Internet. The main components of EPC are the home subscriber server, which is a central database; the PDN gateway (P–GW); which communicates with the outside world, the serving gateway (S-GW), which acts as a router, and forwards data between the base station and the P–GW; and the mobility management entity (MME), which controls the high-level operation of the mobile device by using signaling messages that maintain subscriber profile information.

Takeaways for 5G Vehicular Communications

5G can leverage the existing investments in LTE by extending its capabilities to ensure that 5G is interoperable with 4G LTE and delivers the performance desired by vehicular communications. As a result, some of the features that can be anticipated in 5G for vehicular communications are as follows.

4G LTE provides support for the integration of WiFi and the unlicensed spectrum. This capability will be extended in 5G by integrating systems including, but not limited to, 3G, 4G, WiFi, ZigBee, and Bluetooth. This feature will enable vehicles and passengers to connect seamlessly with the most suitable network to support the specific requirements of safety, non-safety (i.e., TISs), and infotainment (i.e., content sharing) applications.

A recent report has shown that equipment manufacturers around the globe are capable of producing 1.4 million connected car packages a month, which is expected to increase every year (https://www.strategyand.pwc.com/media/file/Connected-car-report-2016.pdf, accessed Sept. 4, 2017). As the number of connected cars on the roads continues to increase, 5G would require innovative strategies such as direct device discov-

5G building blocks	Features	Challenges
Proximity service	• Offloads the base station • Users can advertise, discover, and communicate directly	• Interference at lower altitudes • Interference in same-band transmissions • Spectrum allocation issues
Mobile edge computing	• An architecture that brings cloud computing at the edge • Supports multi-vendor environment • Supports discovery and access of MEC resources	• Availability of all access technology • Cost effectiveness of hosting cloudlets • Consideration of hosting demands (processing, security, etc.)
Network Slicing	• A management architecture to logically separate networks • Includes provisions for multiple control planes for networks	• Challenge of specifying a truly modular approach for slicing networks • Centralized and sliced network identification • Specifying rationale for slicing a vehicular networks (i.e., QOS, QoE, service types, resource provisions etc) • Support for data analytic techniques

Table 2. A summary of 5G building blocks applicable to vehicular communications.

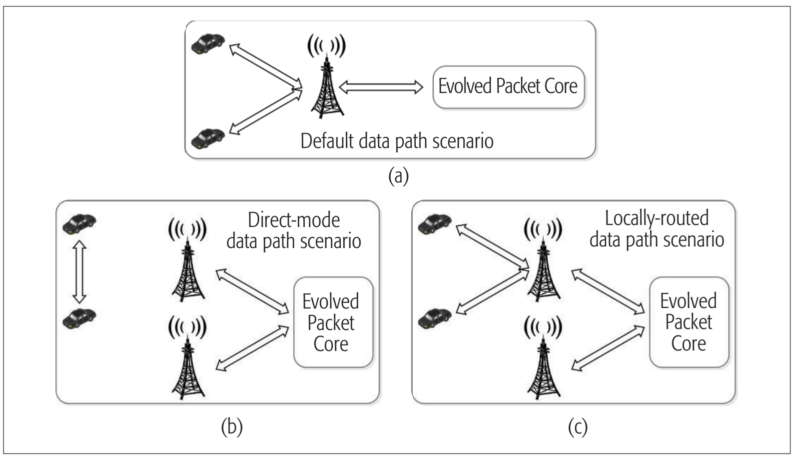

Figure 2. Data path scenarios for ProSe.

ery, node coordination mechanisms, and spectrum sensing in order to increase capacity.

Direct device discovery and communication without the use of infrastructure is already supported by 4G LTE. 5G would require device-to-device communication with greater coverage areas to provide innovative proximity-based services and access to data.

The capacity demands can also be satisfied by the node coordination mechanism. The intercell coordination mechanism is already defined in 4G LTE. 5G can leverage cloud radio access networks for enhanced coordination among base stations. Moreover, 5G plans on more efficient use of spectrum by sharing it among users (primary, secondary, and tertiary).

5G Building Blocks Applicable to Vehicular Communications

This section explores key building blocks of 5G and their associated challenges in context of vehicular communications. The most relevant details are summarized in Table 2.

Proximity Service as a Platform For Beaconing

An important feature of 5G-enabled communications is the proximity service (ProSe) [8]. Currently, the aim of ProSe is to provide awareness by discovering devices and services using relevant locality information. In the context of the 5G-enabled Internet of Things (IoT) [9], ProSe is particularly significant for many spontaneous interactions or communication opportunities within a certain proximity. The key enablers for ProSe-based applications are location information and the communication trends in social networks. Unlike traditional location discovery over the network (e.g., Facebook), ProSe provides ad hoc location discovery and communication opportunities (e.g., moving vehicles on roads). More importantly, with the ability to discover and communicate without an infrastructure, ProSe can be used as a communication platform in public safety scenarios. From a technical viewpoint, such ad hoc discovery and communication among UEs provide a means for high data rate transmissions (i.e., by avoiding latency due to traversing through the core) and high efficiency in resource utilization (i.e., by avoiding transmissions passing through the core network), thereby reducing congestion in the core network.

To elaborate on the key functions of ProSe, all the UEs need to subscribe to an eNB (considering that the coverage is provided by the same eNB, although other configurations are also possible). In this case, any UE can broadcast a service in a desired proximity over the LTE licensed spectrum. All services that are available are discovered by UEs within the coverage area of service advertisements. However, to ensure that only relevant services are discovered, users can use the relevant filters. After service discovery, a UE can pull the advertised content from the 5G network.

We note that vehicular safety applications rely on the accurate location information of the vehicles in close proximity, which is enabled by the periodic exchange of beacons. IEEE 802.11p designates a shared 10 MHz channel in the 5 GHz spectrum for beaconing. Vehicular safety applications require very frequent transmission of beacons in addition to their low latency requirements. For instance, a delayed message for a collision avoidance application may be of no use if it is delivered after the driver reacts to the situation. Recent analysis has shown that the successful transmissions and timely delivery of beacons in large-scale vehicular deployments cannot be guaranteed due to interference and erroneous transmissions. This is largely because of channel saturation in the bandwidth constrained wireless networks.

The shortcomings of IEEE 802.11p can be

addressed using ProSe. Vehicles can discover neighboring entities for communication through the direct mode and/or through the locally routed data path with periodic beacons as shown in Figs. 2a and 2b, respectively. In the vehicular networks scenario, 5G could exploit such communication to provide greater coverage for efficient safety and non-safety applications. Another possible configuration is one where the data path is accessible through the local eNB.

The ProSe provides a solid foundation for vehicular safety communications in a 5G environment. Besides vehicular safety application communication, an important use case is tracking security attack sources in the connected autonomous vehicles (AVs) scenario. Security risks for autonomous driving are unique. As an example, it has been demonstrated that the braking system and the steering system can be remotely controlled (Keen Security Labs; http://keenlab.tencent.com/en/, accessed Sept. 4, 2017). While protecting AVs from remote attacks is possible to some extent using encryption techniques, tracking the source of attack is challenging. This is mainly because periodic messages are broadcast, and their caching is only relevant for a short time. However, the locally routed data path can be exploited for tracing back the attack source. That is, stations can be used for:
1. Caching messages
2. Identifying the source of suspicious messages if an attack event is reported

Wireless communication using unnamed aerial vehicles (UAVs) promises to provide cost-effective communications at high speeds for various use cases, including supporting terrestrial communication systems for capacity improvement, military surveillance, traffic monitoring on roads, and so on. Since ProSe offloads the base station to enable direct communication among UEs, the use of ProSe can save energy for UAVs.

Research Challenges:

Interference at Lower Altitudes: An essential service for vehicles is to discover and communicate with their neighbors frequently [10]. The potential ProSe approach needs to adapt from the base station to vehicle communication to device-to-device communication. This shift in paradigm brings about challenges of radio propagation among vehicles. This is because in the case of vehicles, which are at lower altitudes (i.e., commuting on roads with tall obstacles and buildings along the way), interference is generally higher.

Spectrum Allocation Policies: Another challenge with ProSe is the allocation of the spectrum for vehicles. The allocation can be made dynamic with policies based on the vehicle's perspectives including, but not limited to, the message priority, quality of service (QoS), and security. Besides, a static configuration is also possible in which the eNB can statically allocate spectrum for vehicles. It is worth noting that the vehicles in future 5G scenarios form an integral part of the IoT environments [11], where vehicles would be involved in auxiliary communications besides safety. This has implications on the interference levels of vehicles that use the same band for transmission and reception.

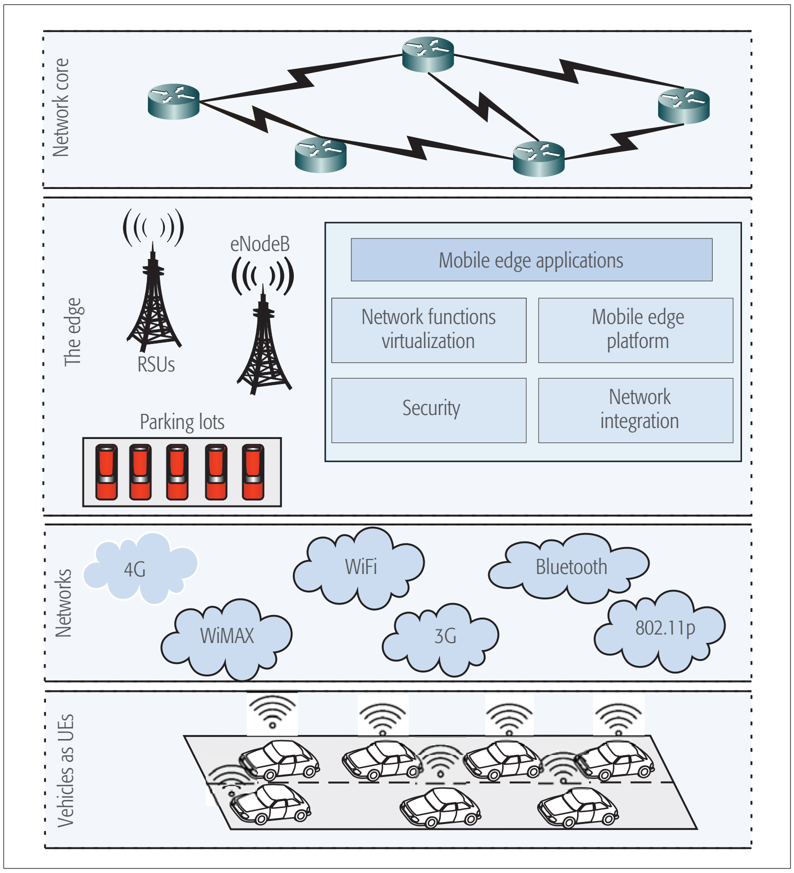

Figure 3. Mobile edge computing scenario for vehicular networks.

Exploiting MEC Resources for Vehicular Communications

MEC will play a fundamental role in 5G [12]. One of the key requirements of 5G-enabled vehicular communications is low latencies (up to 100 ms for safety) and ultra-low latencies (up to 1 ms for AV use cases). One way to achieve such low latencies is to move some of the core functionalities closer to the consumer, that is, the edge. MEC provides a platform for bringing services to the most suitable network locations such as mobile vehicles on roads.

The key functionalities of the edge include a multi-vendor environment that hosts mobile edge applications. As shown in Fig. 3, the availability of different services requires virtualization through network functions virtualization (NFV). The mobile edge platform is responsible for the discovery, access, and advertisement of MEC services. Security is a key feature that ensures the confidentiality of designated services hosted at the core network. Finally, the network integration at the edge offers services for seamless access of MEC during commuting. Some of these aspects at the edge are considered in the recently proposed European Telecommunications Standards Institute (ETSI) MEC framework and reference architecture [13].

Different access technologies (i.e., WiFi, 802.11p, 5G, etc.) can be utilized by vehicles for communication. The edge supports some of the core network functionalities that are hosted from the core network. The existing eNB and/or RSUs with processing and storage capabilities can also be used to host core network functionalities. In

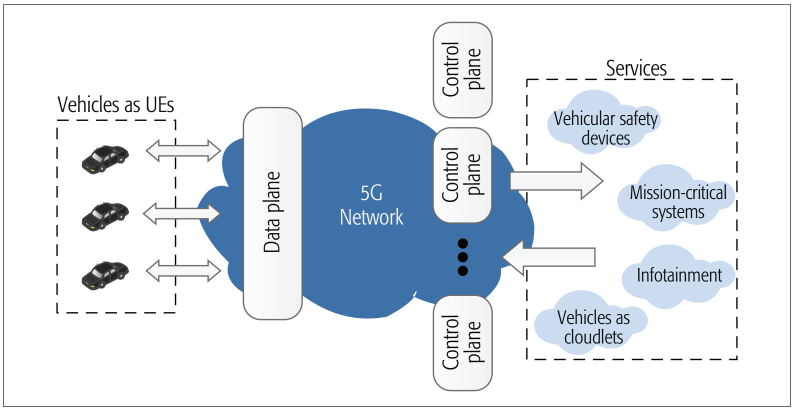

Figure 4. A network slicing perspective of vehicular communications.

the context of vehicular communication, MEC can be crucial for systems such as TISs that have flexible latency requirements. Unlike safety vehicular applications, TIS information does not impose hard latency requirements, and the information is valid for longer periods of time. This flexibility ensures that any improvement in latency using MEC will improve the overall user experience.

Research Challenges:

Handover Management among Heterogeneous Access Networks: While ETSI has designed a basic architecture for MEC, its true potential could be realized by addressing the following challenges. As stated earlier, vehicles on the roads are expected to be connected with multiple networks. Therefore, during mobility, it is highly likely that a vehicle might move out of the coverage of an access network in use to join another. This mandates that the MEC specifications consider support and availability of MEC for multiple access technologies in order to be truly beneficial for vehicular communication use cases.

Cost Effectiveness Edge Deployment: Since the main goal of MEC is to bring services closer to the consumer for reduced latency, the cost effectiveness for large-scale deployment must be considered. This is particularly crucial for vehicular networks because RSUs can also be used for hosting some of the cloud services besides eNB stations. However, deployment of RSUs and eNB stations across complete vehicular networks is costly. Finally, it is also important to consider the requirements of designated hosted services in terms of security and high demands on processing and storage. More importantly, security concerns (e.g., confidentiality) do not allow information, such as driver information, vehicle identifiers, destinations, and routes, traditionally stored in the cloud to be hosted on eNBs/RSUs.

Provisions for Different Vehicular Applications through Network Slicing

Network slicing is a key driver in providing a truly unifying platform for different access technologies. The key challenge in 5G is the management of all the available access networks. Network slicing aims to ease management by logically separating the networks. In particular, the control plane, which is available to the network devices, is split into multiple control planes for specifying the forwarding rules for the designated data plane, as shown in Fig. 4. Technologies such as SDN and NFV can be used for network slicing.

In a vehicular network scenario, different network slices can be designated based on the diversity of application requirements. Safety applications can be specified as a network slice that requires lower latency and highly reliable periodic message transmission. Another logical network slice can be designated for infotainment applications to satisfy their QoS requirements and to enhance user experience with high-bandwidth rich content distribution. As an example, IPTV requires a continuous stream using high-speed Internet connections [14]. Mission-critical system applications can also be assigned a network slice as they require a more spontaneous exchange of information to maintain connectivity with the infrastructure in case of a disaster.

Accessing cloud services from the edge during high mobility also has its own requirements such as offloading compute-intensive applications and receiving timely results. Since vehicles are mobile, another important requirement that must be supported by MEC is its ability to store the process states and to ensure availability of these states to a different access network if a vehicle moves. In addition to the aforementioned requirement, we need to protect the integrity of vehicular networks' data at the edge, which can also be achieved using a separate network slice for better security management.

Research Challenges:

Translating Vehicular Application Requirements into Technical Specifications: The use of network slicing in 5G design opens up a few challenges. Most of the concerns about network slicing arise from its unclear specifications of its operation. For instance, to give a truly modular approach for different sliced networks, vehicular application requirements must be carefully translated and categorized into technical specifications. This will ensure that one sliced network does not affect another, and changes from one slice to another are seamlessly integrated.

Defining Rationale for Network Slicing: Another aspect is the classification of user requirements in order to determine if the network functions need to be centralized or sliced. At present, the technical specifications of network slicing are not very well defined. A possible rationale for slicing a network such as a vehicular network could be based on QoS application (infotainment and Internet access) requirements, types of services available for the vehicles, or available resources.

Need for Data Management and Analytics: In practice, we can expect to have large scale vehicular networks with millions of vehicles, which will generate large amounts of distributed data. This data must be processed and stored in a distributed manner across the vehicular network [15]. Furthermore, the large network size and the amount of generated data, along with the inherent characteristics (i.e., mobility and topology changes) of vehicular networks pose new and unique challenges to data management. Moreover, to be useful for decision making, new data analytics techniques must be developed for the dynamic vehicular network environment.

CONCLUSION

In this article, we provide an overview of the relevant 5G building blocks in the context of vehicular communication. There is a general understanding that the technologies such as ProSe, MEC, and network slicing in 5G along with the new access technology will address some of the deficiencies of IEEE 802.11p. ProSe not only provides a platform for the most desirable safety vehicular communications, but also paves the way toward determining the source of autonomous vehicle attacks. MEC promises to reduce latencies for some vehicular applications such as the traffic information system that have flexible latency requirements. Similarly, by translating the vehicular use case requirements into technical specifications, network slices can be created for services such as the dedicated vehicular safety applications, IPTV with QoS requirements, and emergency response applications.

However, 5G benefits can only be achieved if key performance indicators for the vehicular applications use cases are defined and challenges pertinent to each of the buildings blocks are carefully addressed.

ACKNOWLEDGMENT

M. Imran's work is supported by the Deanship of Scientific Research at King Saud University through Research Group No. 1435-051.

REFERENCES

[1] D. Soldani and A. Manzalini, "Horizon 2020 and Beyond: on the 5G Operating System for a True Digital Society," *IEEE Vehic. Tech. Mag.*, vol. 10, no. 1, 2015, pp. 32–42.
[2] T. S. Rappaport *et al.*, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!" *IEEE Access*, vol. 1, no. 1, 2013, pp. 335–49.
[3] R. A. Uzcátegui, A. J. De Sucre, and G. Acosta-Marum, "Wave: A Tutorial," *IEEE Commun. Mag.*, vol. 47, no. 5, May 2009, pp. 126–33.
[4] G. Araniti *et al.*, "LTE for Vehicular Networking: A Survey," *IEEE Commun Mag.*, vol. 51, no. 5, May 2013, pp. 148–57.
[5] I. Yaqoob *et al.*, "Overcoming the Key Challenges to Establishing Vehicular Communication: Is SDN the Answer?" *IEEE Commun. Mag.*, vol. 55, no. 7, July 2017, pp. 128–34.
[6] S. A. A. Shah *et al.*, "Adaptive Beaconing Approaches for Vehicular Ad Hoc Networks: A Survey," *IEEE Systems J.*, 2016, pp. 1–15.
[7] F. Chiti *et al.*, "Communications Protocol Design for 5G Vehicular Networks," *5G Mobile Commun.*, Springer, 2016, pp. 625–49.
[8] X. Lin *et al.*, "An Overview of 3GPP Device-to-Device Proximity Services," *IEEE Commun. Mag.*, vol. 52, no. 4, Apr. 2014, pp. 40–48.
[9] A. Al-Fuqaha *et al.*, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Commun. Surveys & Tutorials*, vol. 17, no. 4, 2015, pp. 2347–76.
[10] M. J. Booysen, S. Zeadally, and G.-J. Van Rooyen, "Survey of Media Access Control Protocols for Vehicular Ad Hoc Networks," *IET Commun.*, vol. 5, no. 11, 2011, pp. 1619–31.
[11] E. Ahmed *et al.*, "Internet-of-Things-Based Smart Environments: State of the Art, Taxonomy, and Open Research Challenges," *IEEE Wireless Commun.*, vol. 23, no. 5, Oct. 2016, pp. 10–16.
[12] A. Ahmed and E. Ahmed, "A Survey on Mobile Edge Computing," *Proc. 2016 10th Int'l. Conf. Intelligent Systems and Control*, Jan. 2016, pp. 1–8.
[13] A. Gharaibeh *et al.*, "Smart Cities: A Survey on Data Management, Security and Enabling Technologies," *IEEE Commun. Surveys & Tutorials*, vol. PP, no. 99, 2017, pp. 1–1.
[14] S. Zeadally, H. Moustafa, and F. Siddiqui, "Internet Protocol Television (IPTV): Architecture, Trends, and Challenges," *IEEE Systems J.*, vol. 5, no. 4, 2011, pp. 518–27.
[15] J. Contreras-Castillo, S. Zeadally, and J. A. G. Ibaez, "Solving Vehicular Ad Hoc Network Challenges with Big Data Solutions," *IET Networks*, vol. 5, no. 4, 2016, pp. 81–84.

BIOGRAPHY

SYED ADEEL ALI SHAH is working as an assistant professor of computer science at the University of Engineering & Technology, Peshawar, Pakistan. He received his Ph.D. in computer science from the University of Malaya, Malaysia. He also holds a Master's in computer and information networks from the University of Essex, United Kingdom. He is investigating architectures to enable reliable vehicular communications powered by 5G. He is interested in vehicular ad hoc networks, IoTs, SDN, MEC, and network slicing.

EJAZ AHMED [S'13, M'17] received his Ph.D. (computer science) from the University of Malaya in 2016. He is an Associate Editor of *IEEE Communication Magazine*, *IEEE Access*, *KSII TIIS*, and *Elsevier JNCA*. His areas of interest include vehicular networks, big data, mobile cloud computing, mobile edge computing, the Internet of Things, and cognitive radio networks. He has also received a number of awards during his research career.

MUHAMMAD IMRAN is currently working at King Saud University, Saudi Arabia, and as a visiting scientist at Iowa State University. His research interests include MANETs, WSNs, WBANs, M2M/IoT, SDN, security, and privacy. He has published a number of research papers in refereed international conferences and journals. He serves/has served as a Co-Editor-in-Chief for *EAI Transactions* and Associate/Guest Editor for *IEEE Access*, *IEEE Communications Magazine*, *Computer Networks*, *Sensors*, *IJDSN*, *JIT*, *WCMC*, *AHSWN*, *IET WSS*, *IJAACS*, and *IJITEE*.

SHERALI ZEADALLY is an associate professor in the College of Communication and Information at the University of Kentucky. He received his Bachelor's degree in computer science from the University of Cambridge, England, and his doctoral degree in computer science from the University of Buckingham, England. He is a Fellow of the British Computer Society and the Institution of Engineering Technology, England.

By translating the vehicular use case requirements into technical specifications, network slices can be created for services such as the dedicated vehicular safety applications, IPTV with QoS requirements and emergency response applications. However, 5G benefits can only be achieved if key performance indicators for the vehicular applications use cases are defined.