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Chapter

Improving Communication System for Vehicle-to-Everything Networks by Using 5G Technology

Tarik Adnan Almohamad, Muhammet Tahir Güneşer, Mohd Nazri Mahmud and Cihat Şeker

Abstract

Next-generations of wireless communication systems (5G scheme & beyond) are rapidly evolving in the contemporary life. These schemes could propose vital solutions for many existing challenges in various aspects of our lives, eventually to ensure stable communications. Such challenges are even greater when it comes to address ubiquitous coverage and steady interconnection performance in fast mobile vehicles (i.e., trains or airplanes) where certainly blind spots exist. As an early initiative, the Third Generation Partnership Project (3GPP) has proposed a regulation for Long Term Evolution (LTE)-based Vehicle-to-Everything (V2X) network in order to offer solid solutions for V2X interconnections. V2X term should comprise the following terminologies: vehicle-to-vehicle (V2V), vehicle-to-network (V2N) communications, vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P). Superior V2X communications have a promising potential to improve efficiency, road safety, security, the accessibility of infotainment services (any service of user-interface exists inside a vehicle). In this chapter, the aforementioned topics will be addressed. In addition, the chapter will open the door on investigating the role of wireless cooperative and automatic signal identification schemes in V2X networks, and shedding light on the machine learning techniques (i.e, Support Vector Machines (SVMs), Deep Neural Networks (DNNs)) when they meet with the next-generations of wireless networks.

Keywords: Next-Generations of Wireless Communication Systems, Long Term Evolution, 5G scheme, Vehicle-to-Vehicle Communication, Vehicle-to-Everything, Automatic Signal Identification, Deep Neural Networks

1. Introduction

Artificial intelligence (AI)-based communication applications have shown a tremendous upsurge in the late decade. It is triggering an exceptional attention from academia, governments and diverse industry sectors on the evolving generations of wireless networks. The imminent coming application of fifth generation (5G) wireless communications scheme has spurred the question what is next?. Research sectors have recently started to investigate what is beyond 5G and envisage the upcoming sixth generation (6G). The work in [1] has paved the way for a more detailed exploration of possible methodologies of AI-empowered 6G communication systems and their unprecedented makeover in their architectures compared to the preceding versions of

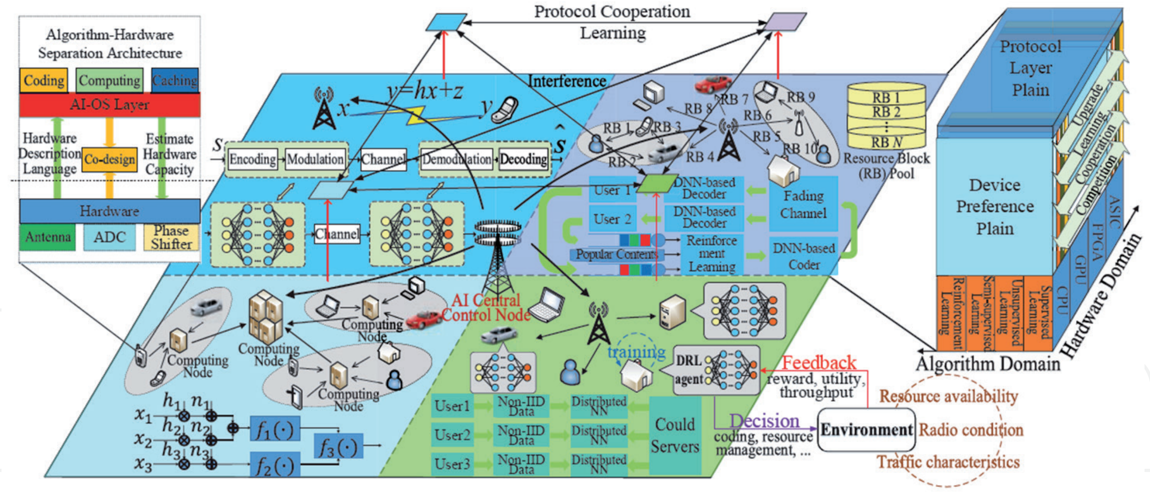

Figure 1.
Potential network design for future generation of wireless networks [1].

wireless networks. **Figure 1** illustrates a world of *connected things*, and the vision for the future generation wireless networks [1]. The future generation of wireless communication systems will unleash a remarkable advancement in wide range of applications such as, but not limited to, vehicles networking, wireless cooperative systems in drones, intelligent cities, etc. As connected things result in heterogeneous complicated networks, this in turn, necessitates the need of AI empowerment in the telecommunication sector.

Now, time has come for academia and manufacturing sectors to bring their focus on the potential applications of the coming generations of wireless communication systems in various aspects of our lives. It can be observed that multiple countries have been starting to apply the new generations of communications i.e., fifth generation (5G) wireless communications scheme. Today, the current promises in telecommunication sector for 5G tell that, firstly the deployment of 5G is ongoing now, prominent low levels of latency, significant increment in capacity, higher speeds of transmissions rate, device-to-device (D2D) communication and of course connected V2X networks, and internet of everything (IoE). Intensive progress is currently witnessed for the transition from the Long-Term Evolution (LTE) to 5G systems in the communication industry. With this momentum, V2X has garnered more considerable attraction today [2], it has the ultimate potential into the enhancement of transportation efficiency, road safety and security, forming a key platform for transportation systems. Such systems intend to be more efficient and intelligent when next-generation communication schemes (5G & beyond) are involved. 5G-based V2X communications can accelerate the advancement of the intelligent transportation systems and reduce traffic and road risks. In V2X schemes, the connected vehicles can aggregate more information about the road environment condition and communicate this valuable information with adjacent vehicles in a real-time scenario. This will lead to an accurate estimation of a risky event before its occurrence. Originally, before this collaboration among vehicles, an internal sensor unit like a global positioning system (GPS) or radar device was envisioned to generate and provide information about vehicle-surrounding environment. Today, the emergence of 5G & beyond communications schemes is promising to efficiently facilitate collaborative connections among vehicles. Back to LTE systems, the Third Generation Partnership Project (3GPP) worked on completing the standardization of LTE-based V2X in their Release 14 to support the automotive industry with LTE services [3]. In Release 16, 3GPP has developed the 5G New Radio (NR) to provide V2X services much more superior than the facilities provided by LTE networks earlier [4]. Normally, Mobile units in cellular networks are connected via one or more base stations but with 5G NR scheme, these unites are connected directly by using what is called sidelink communication technology. Thus, 5G-assisted vehicles will be able to form their ad hoc systems, leaving the need of any extra radio access equipment as an interface among them. On the other hand, in contrast to LTE sidelink, plateau of services are offered by NR sidelink such as collision prevention, unicast and groupcast transmission, QoS administration, cooperative lane switching, compatibility in mm-wave frequency bands, etc. **Figure 2** illustrates V2X communication scenario. The figure depeicts various potential events that may occur among vehicles in real time, the roadside unit (RSU) can relay the received information and deliver them to a vehicle or a group of vehicles supporting V2I applications. This transportation system tends to be more intelligent when V2X scheme is applied as it enables less traffic, collision avoidance, real time data collection [5].

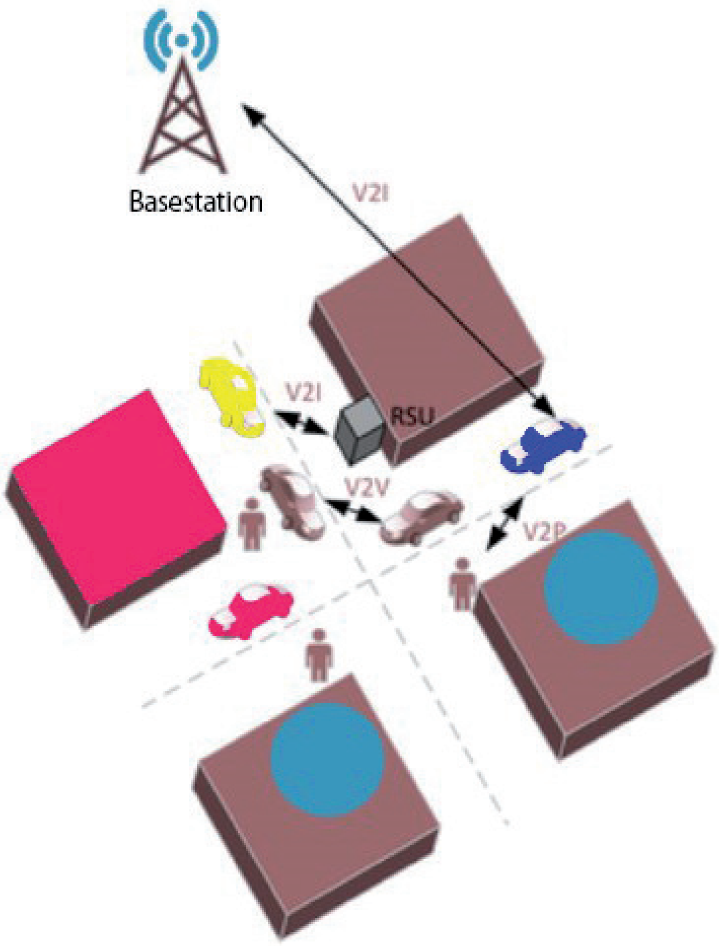

Figure 2.
V2X communication environment with roadside unit (RSU).

According to the European Telecommunications Standards Institute (ETSI), V2X communication messages are categorized into two groups: decentralized environmental notification messages (DENMs) [6] and cooperative awareness messages (CAMs) [7]. These messages convey information about the vehicle condition such as direction, position, velocity, and acceleration, etc. **Figure 3** portrays a scenario on how vehicles being instantly assisted by warning messages. In addition, LTE\5G NR enable exchanging these V2X-messages in unicast and broadcast carriers (bearers) whereas acknowledging the message delivery is executed, at the physical & MAC layers, by the network (i.e. base station). This acknowledgment feature can efficiently minimize the retransmission rate of V2X communication messages. Detected situations will generate DENMs to warn road drivers whereas the periodic CAMs to update the condition within up to 100 *ms* of latency.

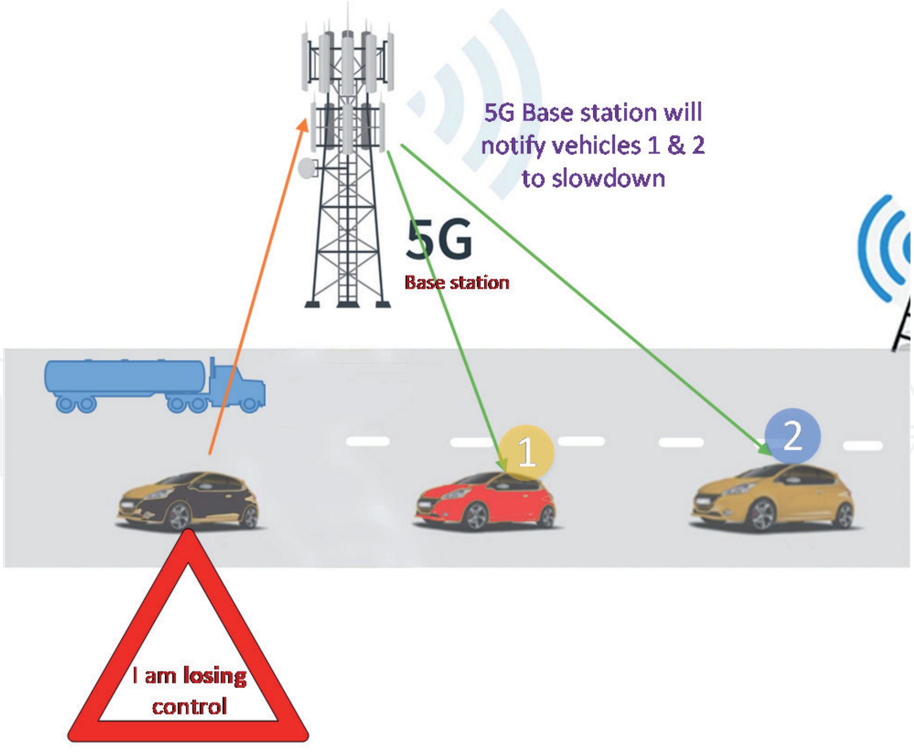

Figure 3.
The 5G base station broadcasting warning messages to vehicles on trajectory.

In June 2016, the use cases and related key requirements for enabling LTE network to serve V2X communications, were identified by Technical Specification Group (TSG) and System Aspects Working Group 1 (SA1). They classified the use cases in 3GPP into safety and non-safety use cases. The former focusing on securing life and objects, and collision avoidance, the latter use cases aiming the enhancement of environmental performance and transportation movement. Nevertheless, 3GPP has carried out a comprehensive revision of V2X service requirements and enhanced them by proposing NR Release 16 [8, 9]. There are four areas of V2X possible events, have been defined in [9] (i.e., platooning, advanced driving, extended sensor, and remote driving). The following **Table 1** maps these four areas into various 3GPP technologies.

Practically, most of the requirements mentioned in **Table 1** have been already attained by 5G Release 15 cellular downlink and uplink. On the other hand, remote driving demands optimal QoS requirements i.e., extremely small latency values and higher levels of reliability which are abbreviated as ultra-reliable low-latency communication (URLLC). In order to meet these demands, 3GPP has extensively worked on improving the reliability and reducing the latency of the cellular downlink and uplink [10] in Release 16, by considering the following procedures:

a. Enable more stable and solid transmissions by improving the downlink control channel information (CCI).

b. Enable prompt feedback of hybrid automatic repeat request (HARQ) by refining the uplink CCI.

c. Empower instant communication by enabling multiple configurations to the uplink and downlink scheduling.

d. Support the recurrence of short-range communications by improving the uplink data channel.

Use case field	Use cases	QoS necessities			Technical enablers
		Data rate [Mb/s]	Reliability [%]	Latency [ms]	
Driving group of vehicles together (platooning)	Sharing information among the vehicle group and with other groups	65	99.99	10	LTE or 5G broadcast (for limited cases), 5G groupcast or unicast
Advanced driving	Data sharing, Cooperative crash prevention, Vulnerable driver recognition, Emergency trajectory alignment	53	99.999	3	5G broadcast/ groupcast/unicast
Extended sensor	Collective perception of environment, Transparency	1000	99.999	3	LTE broadcast, 5G broadcast
Remote control	Drive a vehicle remotely	Uplink: 25, Downlink: 1	99.999	5	LTE or 5G unicast via cellular interface

Table 1.
3GPP considerations for V2X use cases [4].

e. Ease transmissions of critical packets at crucial levels of latency by prioritizing intra-vehicles and inter-vehicles packets

The above procedures will lead to the betterment of reliability and latency of V2X communications. Thus, 5G communication scheme (including LTE & NR Release 16) can increasingly enhance the V2X use cases covering those ones that require high levels of reliability and low latency.

2. Fifth generation (5G)-based V2X working situations

3GPP has been actively worked on specifying the 5G radio interface or as referred to as NR, aiming to achieve more flexible spectrum with higher frequency operations. This is due to the need of deploying radio access technologies and enlarging the spectrum range.

In order to ensure a reliable communication among vehicles and avoid any outage effect from the network, 3GPP, in its Release 16, proposed device-to-device link in NR called sidelink [11]. The proposed sidelink enjoys multiple advantages such as:

a. Flexible radio link benefiting from the exiting NR cellular interface.

b. Operates in unlicensed and licensed frequencies' ranges, hence, it can be allocated for V2X facilities and even shares with existing mobile network services.

c. Enables V2X use cases for unicast and broadcast transmission among vehicles themselves.

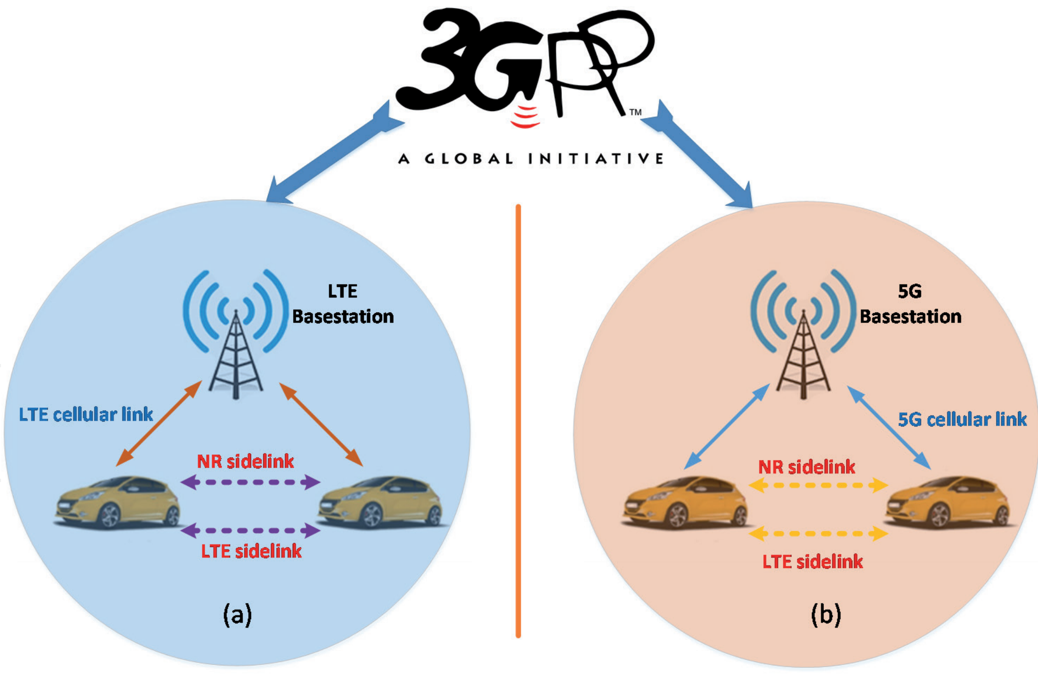

Figure 4.
Illustration of (a) LTE sidelink mechanism, and (b) 5G sidelink mechanism.

d. Gives a space to the network to allocate and control the sidelink resource.

e. Offers instant V2X services by the coexistence of NR and LTE sidelinks.

f. Operates in dual ranges of frequencies, lower (FR1) and higher (FR2) frequency bands i.e., 7.125 GHz and 52.6 GHz respectively.

g. Enables vehicles to connect with each other regardless the condition of the base stations in the network.

The design of NR inherently includes capabilities that support the user equipment to control the sidelink transmissions in the network. This, together with cellular transmissions, leads to share the existing available frequency bands. The aforementioned discussion can lead us to the fact that there are two transmission scenarios termed as mode 1 and mode 2. The former is active when decisions are given and centralized by the network. The latter operates in the case when base station system goes down.

Figure 4 shows potential scenarios of 5G (i.e., NR) and LTE with V2X networks. A base station can be classified into LTE or 5G station, depending on its connected core. As illustrated in the figure, the base station can configure all the cellular links and sidelinks over the network.

3. Wireless access in vehicular environment (WAVE)

WAVE is a group of wireless standards that are represented by the Dedicated Short Range Communications (DSRC) protocol such as IEEE 802.11p and IEEE 1609 standards [12]. This protocol, to support V2X networks, is being defined by IEEE and ETSI in collaboration with the automotive industry sector. The main idea behind DSRC protocol is the provision of road safety in V2X networks. Furthermore, academia, industries and governments have supported many projects to utilize DSRC in fulfilling V2X applications.

The IEEE 802.11p, which belongs to IEEE 802.11 family, is considered as a base to the V2X communication networks due to its high security levels. Moreover, road safety applications such as crucial exchange of real-time data among fast-moving vehicles, and many more of Intelligent Transport System (ITS) platforms, are supported by IEEE 802.11p protocol.

Figure 5 portrays the WAVE stack, which has multiple layers and protocols. On the top WAVE stack, there is application layer (APPL) which is responsible for resource management and handling diversity of non-safety and safety applications. Under this layer, there are three essential sublayers, that is, user datagram protocol (UDP), transmission control protocol (TCP) and internet protocol version 6 (IPV6) sub-layers. They are part of the main WAVE short message protocol (WSMP) layer. Then, the logic link control (LLC) layer, WAVE MAC layer, and eventually the WAVE physical layer which essentially supports the higher layers [13–15].

It is crucial to mention that possessing a very flexible and reliable design of WAVE physical layer will ensure optimum throughput and extremely lower latency. This can be realized in the upcoming 5G communication scheme and its proposed NR sidelinks.

In fact, the structure of sidelink protocol between LTE and 5G is nearly common. However, as illustrated in **Table 1** before, the focus on quality of services' issues is much more vital in 5G sidelink than in LTE as enhancing the V2X use cases is an essential goal in this new cellular paradigm. In contrast to LTE, the 5G sidelinks are envisioned to provide more flexibility in efficient utilization of existing resources and superior adaptability to various mobility situations. These potentials are attributed to significant privileges of 5G sidelink, involving:

a. A power control procedure to alleviate interferences among V2V sidelink and base stations.

b. Radio link adaption based on sensing channel condition.

More details will be elaborated in subsequent sections on signal identification techniques in next-generations wireless communications.

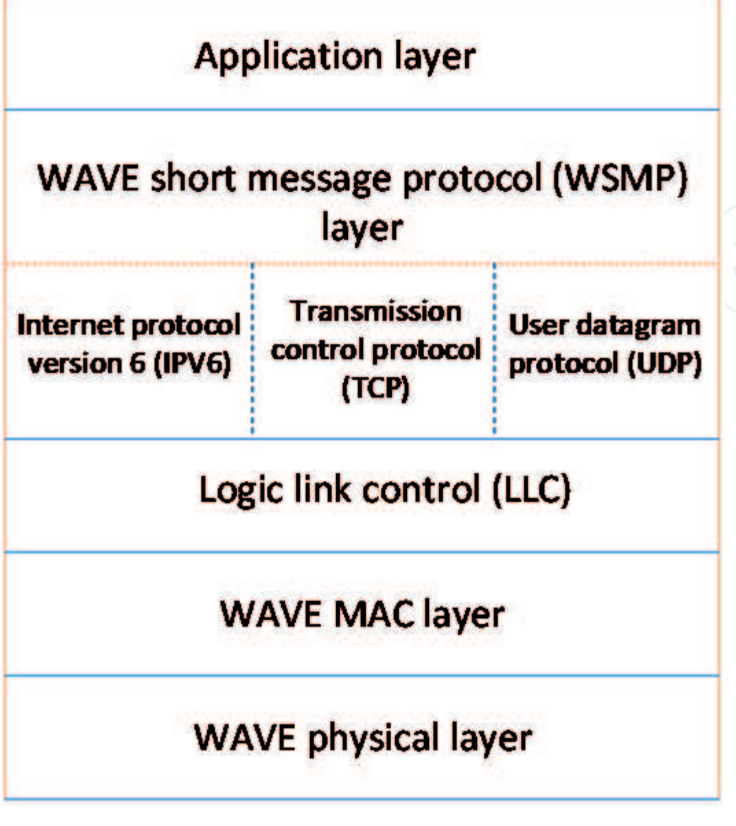

Figure 5.
Wireless access in vehicular environments (WAVE) stack.

4. Signal recognition in V2X using artificial intelligence (AI) techniques

Next-generation communication networks are envisioned to go more intelligent in the coming decade. Transmitters and receivers in any such networks are anticipated to work in adaptive mode when these devices are able to sense the communication medium (i.e., wireless channel) status between them. Based on the channel condition i.e., signal to noise ratio (SNR) value, the transmitter can decide the optimum transmitted signal parameters before the implementation of transmission process. For example, bit rates, modulation type, SNR level, transmitted power, and so on, can be adjusted by the transmitter, depends on the current environment status. It will monitor the channel condition, if it is good, then parameters such as less transmitted power, is required, or higher modulation schemes can be considered, hence higher transmission data rates can be achieved. This, in turn, requires the other receiving side to adapt to such unexpected changes and correctly estimate the parameters used to transmit the signal by the sender. Artificial intelligent (AI) tools can play a significant role to facilitate this estimation process [16]. On the other hand, it is promising that AI-based V2X communication systems will enable more safety, traffic efficiency, awareness & automotive driving, and security in the vehicular industry. When AI meets the emergence of 5G & beyond communication systems, the way is more paved to smart transport networks [17]. These networks will definitely bring a new concept of connectivity among vehicles and have a profound influence on our daily life. Furthermore, the deployment of 5G communication systems in V2X networks will bring this paradigm to higher efficiency and safety level.

As in traditional mobile networks, there are both transmitter and receiver nodes to exchange the data. Similarly in V2X communication networks, there are these nodes (i.e., vehicles) to exchange instant information. In the transmission process, a vehicular transmitter will modulate the data and send the modulated signal via the communication channel to the vehicular receiver side. A smart vehicle in 5G-based V2X network is anticipated to adapt to the channel condition and optimally adjust the modulation type or transmitted power suitable for transmission. This, in turn, will necessitate the vehicular receiver to adapt itself to these unexpected changes and recognize the signal parameter i.e., modulation being used at the transmitter side. Accurate recognition of V2V signal's parameters can be very beneficial to many use cases in the vehicular networks. In addition, it can be utilized as a source of information for the base stations to update many instant and vital data such as the position of moving vehicles, awareness messages, and information related to road environment.

For the purpose of meeting such demands, vehicular networks utilized indexed modulation (IM) techniques for data transmission [18]. IM method (i.e., spatial modulation) uses indices of the building modulated blocks (i.e., transmit antennas) in a communication scheme (i.e., MIMO systems). The following block diagram illustrates the key idea of IM technique as shown in **Figure 6**.

As illustrated in the figure, first, the input data is projected into a common vector before splitting it into two sub-vectors. They are dedicated to distinct transmit indices and then mapped to a digital modulation symbol such as phase shift keying (PSK) or quadrature amplitude modulation (QAM). Eventually, the common vector is mapped to IM vector for the purpose of transmission.

The decision of choosing which digital modulation type is suitable, can significantly affect the vehicular network throughput. In conventional transmission, the receiver will have a pre-knowledge about the selected modulation type, the channel condition, the transmitted power, the bit rates and so on. As mentioned earlier, a vehicle in advanced generations of vehicular communication systems is anticipated to go more intelligent in sensing the wireless channel condition and adjusting these parameters accordingly. In other words, to determine the optimal signal parameters (modulation type, bit rates, transmitted power, etc) before transmission takes a

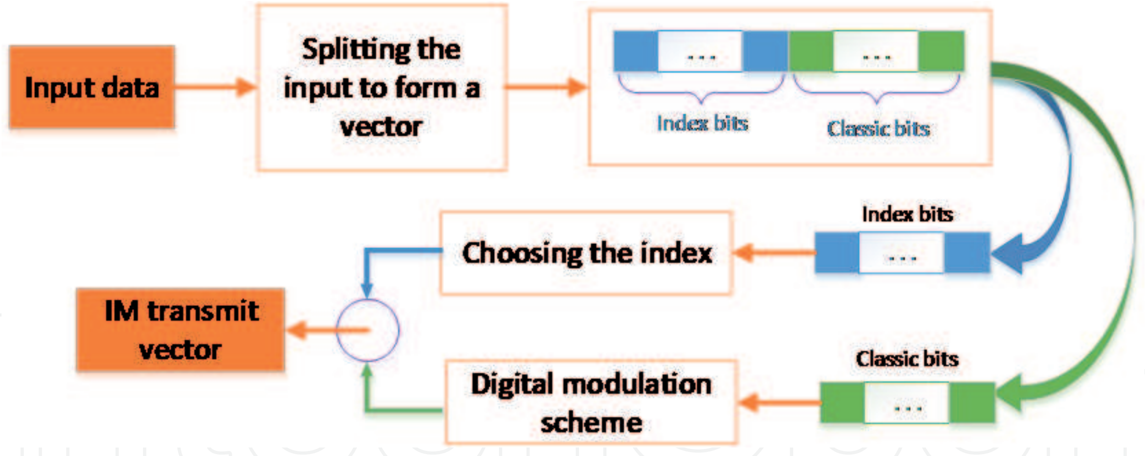

Figure 6.
The key principle of IM process.

place. In this scenario, the vehicular receiver has to track these possible changes and automatically recognize these signal parameters without any pre-communication with the transmitter. This capability at the receiver side, will exempt the vehicular transmitter to broadcast these valuable information over a wireless channel, and this means adding another good level of security to such information.

In order to enable the receiver with an accurate automatic recognition property of signal parameters i.e., automatic modulation recognition (AMR), two key approaches are used and have been reported in literature, that is, maximum likelihood (ML) approach and feature-based (FB) approach [19, 20]. The former provides optimal solution but suffers from higher computational complexity whereas the latter offers sub-optimal results but with lower complexity as illustrated in **Figure 7**. Hence, in this chapter, the FB approach is considered. After careful scanning of existing work in V2X networks, it is worth to mention that, to the best of our knowledge, the recognition of wireless signal parameters has not yet been addressed in the literature.

In ML approach, the values of likelihood functions are calculated and compared with a reference value to finalize the optimal modulation. On the other hand, in FB approach, the statistical characteristics of the received signal are extracted and utilized to estimate the intended signal parameters. There are numerous types of

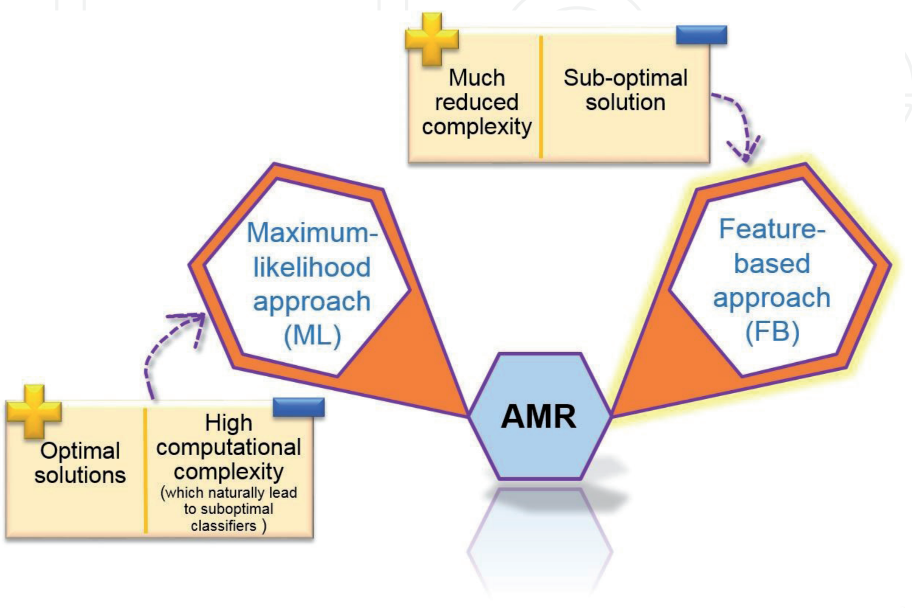

Figure 7.
ML and FB methods used for wireless signal parameter recognition.

features can be exploited to recognize the modulation type of a detected signal such as, instantaneous time-domain features, fourier and wavelet transforms, higher-order statistics, asynchronous amplitude histograms (AAHs), two-dimensional histogram of asynchronous sampled in-phase-quadrature amplitudes (2D-ASIQHs), and so on.

For instance, AAHs features have proved a prominent cost-effectiveness, flexibility and lower computational and implementation complexity. We have applied this type of features before in our work in [21] to estimate multiple signal parameters together using support vector machines (SVMs). It has shown a phenomenal performance to distinguish signals from each other in a realistic cellular wireless environment. Furthermore, SVM has proved its capability in processing small size of datasets compared to other machine learning tools. To clarify the conceptual meaning of AAHs features to the readers, the following **Figure 8** depicts the idea.

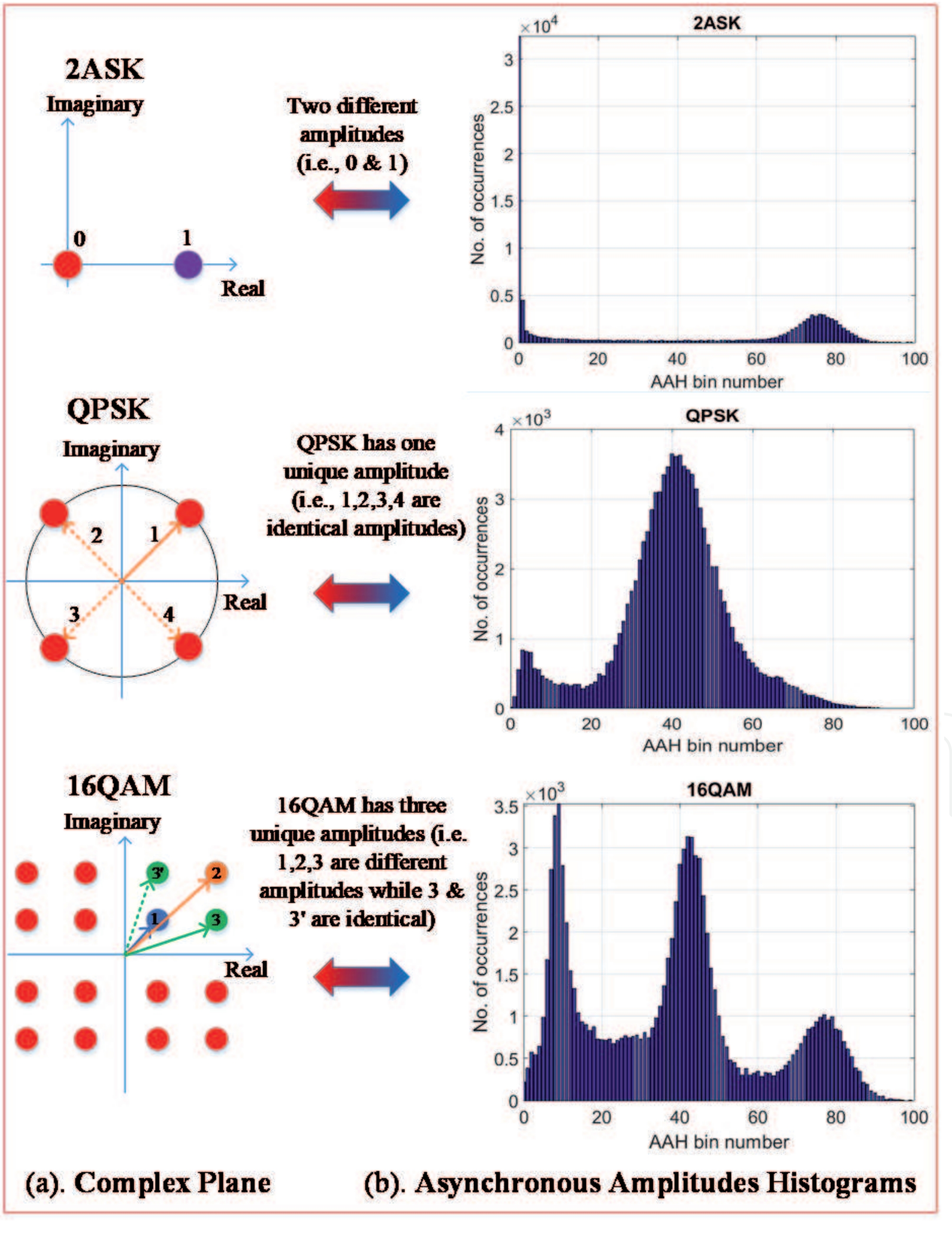

Figure 8.
The main idea of AAHs-based signals (three different modulations i.e., ASK, QPSK, and 16QAM) [21].

As illustrated in **Figure 8**, the main constellation diagrams of three different signals and the corresponding AAHs are shown. Asynchronous shift keying (ASK) has two constellation levels (0 and 1), therefore, two unique peaks appear in the corresponding histogram. But, the case is different in the second histogram for the quadrature-PSK, where one unique peak exists. This is due to the existence of single equal amplitude for the four constellation points in the related constellation diagram. In 16QAM modulation, AAHs show different shape than in the previous two signals. As portrayed in the complex plane for this type, there are 16 points of constellations but only three unique amplitude levels exist, and this interprets why we have three amplitude levels in the corresponding AAH for this signal. We can conclude that AAHs feature demonstrates distinctive signatures among various digital modulations of detected signals. This, in turn, will facilitate the job of the receiver node in the network to automatically recognize the type of modulation being used by the transmitter node leaving the necessity to obtain this information from the transmitter vehicle beforehand.

In the subsequent procedure, the aforementioned features will be fed into a machine learning tool as an input vector in order to enable autonomous recognition at the receiver terminal in the vehicular network. Machine learning tools have found a versatile deployment in different aspects of our lives. They construct smart systems to experience challenging environments. Moreover, they process large quantity of data generated from multiple resources, to extract useful and unique models that can be efficiently utilized in intelligent telecommunications terminals [17]. AI (i.e., machine & deep learning) techniques are still an attractive research direction in the vehicular communication to be more explored. They have the potential to enable data-driven decisions and offer exceptional services in the vehicular networks such as instant traffic control and estimation, position-based facilities, and of course, autonomous driving. Basically, machine learning tools can be broadly classified into two main groups. One called supervised learning machine, the second one is unsupervised machine. The former requires a training process for the classifier\ regressor whereas the latter does not use training subset and usually its task is for clustering and dimension reduction process.

Artificial intelligent (AI) tools have been regarded as a key solid solution to the challenges experienced by self-driving vehicles, such challenges are heavy rain, dense fog or snow, and any other difficult hostile weather conditions. For instance, authors in [22] have proposed a novel scheme to enable awareness and clear vision in automated cars of their surroundings. They deployed deep neural network in combination with the automatic white balance joined with laplacian pyramids (AWBLP) technique in order to enhance the contrast and resolution of the captured vehicle image. For a missed or wrong detection in the adverse condition of weather, they proposed an online tracking system and constructed a dataset which can serve as a benchmark called, detection in adverse weather nature (DAWN) aiming to examine their proposed system. Sample images of the DAWN dataset, before restoration, are shown in **Figure 9** where this dataset covers four challenging weather conditions for automatous vehicles.

The images in this dataset will be restored to enhance their resolution and then to be input into the deep learning tool. This is to perform an online detection of the vehicles and enable them to see each other in difficult weather conditions, and therefore to increase the road safety. However, we have enhanced the resolution of the sample images in **Figure 9** just to add more clarity and visibility for the reader as reflected in **Figure 10**. More challenges will be overcome in the industry domain with such current proposed panacea like DAWN and AWBLP. However, more investigations on other deep learning types, their parameters and their performance to serve cellular V2X networks are still demanded.

Figure 9.
Different groups of images that describe four challenging weather conditions in DAWN dataset.

Figure 10.
Samples from DAWN dataset after enhancing their resolution.

5. Conclusion

This chapter has offered an insight to the scientific community about the potential enhancement of V2X schemes by the deployment of 5G communication network. Let recap what have been addressed earlier, the 5G & beyond wireless systems will enable vehicles to talk to each other and to different infrastructures. Furthermore, the latest advancements in 3GPP enable deploying 5G as a great communication paradigm for V2X networks. In addition, the 5G sidelinks offer unicast, groupcast and broadcast transmission in vehicular communication networks. Furthermore, 5G & beyond systems can enhance the DSCR for collision-free and road safety. With the emergence of 5G technology, the cellular V2X networks will track the momentum and gain more capabilities and connectivity.

The chapter has also paved the way to a prospective research direction on signal recognition schemes (i.e., AMR & SNR) in V2X communication networks. Furthermore, it shed light on their potential techniques and the significance of their role in V2X networks in increasing security levels and enhancing V2V communication system throughput. However, further investigation on identifying many other parameters is required. For instance, a vehicular node in future intelligent V2V networks is envisaged to go adaptive and vary the transmitted power or transmission data rate when sensing the wireless channel.

On the other hand, simultaneous recognition of multiple signal parameters of a vehicle in V2X networks remains a future challenge in the V2X future development. Besides, issues related to wider coverage range utilizing wireless cooperative communication schemes; and matters concerned about higher levels of security in V2X networks with arising complexity of densely connected things will be attractive topics in the near future.

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Abbreviations

V2X	Vehicle-to-Everything
V2V	Vehicle-to-Vehicle
5G	Fifth-Generation
SVM	Support Vector Machine
LTE	Long-Term Evolution
DNN	Deep Neural Network
IoE	Internet of Everything
6G	Six-Generation
3GPP	Third Generation Partnership Project
D2D	Device-to-Device
GPS	Global Positioning System
RSU	Roadside Unit
QoS	Quality of Service
ETSI	European Telecommunications Standards Institute
NR	New Radio
CAM	Cooperative Awareness Message
TSG	Technical Specification Group
SA1	System Aspects Working Group 1
CCI	Control Channel Information
HARQ	Hybrid Automatic Repeat Request
FR1	Lower Frequency Band
FR2	Higher Frequency Band
WAVE	Wireless Access in Vehicular Environment
ITS	Intelligent Transport System
UDP	User Datagram Protocol
IPV6	Internet Protocol Version 6
IM	Indexed Modulation
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
AMR	Automatic Modulation Recognition
ML	Maximum Likelihood Approach
FB	Feature-Based Approach
AAH	Asynchronous Amplitude Histogram
2D-ASIQH	Two-dimensional Asynchronous Sampled In-phase-Quadrature Amplitude
AWBLP	Automatic White Balance Joined with Laplacian Pyramid
DAWN	Detection in Adverse Weather Nature

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