State of the Art: A Review on Vehicular Communications, Impact of 5G, Fractal Antennas for Future Communication

Abdul Rahim, Praveen Kumar Malik and V. A. Sankar Ponnapalli

Abstract In recent years, there is an advancement towards the applications of vehicular communications and leading research area as there is a lot of scope regarding enhancing safety measures, mobility, security and comfort. As the technology is moving ahead towards the 5G, there is a direct impact on the future of vehicular communications. In this paper, we will discuss the various applications of vehicular communication, the antennas used for the communication using 5G technology and the impact of Internet of vehicles. We will also present the impact of fractal antennas towards 5G and vehicular communication applications and various emerging areas in the domain of autonomous vehicles.

Keywords 5G · Vehicular communication · Mobility · Autonomous vehicles

1 Introduction

History goes backwards to the first prototype of the automated highway system which was introduced for the improvement in safety, comfort, speed and efficiency [1]. Back days these were the four basic objectives on which the entire automation system was developed. As the era changes, many more objectives were introduced such as road safety, time management, accident avoiding systems and smart traffic lights with ambulance priority [2].

To accommodate these many smart features for the vehicles, there is an immense need of the bandwidth and the latest technology for multi-band features. The vehicular system should accommodate in GSM-1800/1900, along with DCS-1800 (digital communication system), PCS-1900 (personal communication service), UMTS

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(Universal Mobile Telecommunications System), LTE2600 (Long-Term Evolution), radio band ISM 2.4G (Industrial, Scientific, and Medical), WLAN (wireless local area network), Bluetooth, WiMAX (Worldwide Interoperability for Microwave Access), IEEE802.11p protocol based Vehicle-to-everything, DSRC (dedicated short-range communications) and WAVE (wireless access in vehicular environments) communication bands [3].

As the communication can be handled between vehicles, vehicle to network/infrastructure, vehicle to devices and vehicle to everything, there is a need of direct communication as well as multi-hop communication. With the emerging concepts of millimetre wave, where the radio frequency spectrum ranges from 30 to 300 GHz, which is much higher than the present spectrum range of below 6 GHz [4]. We will discuss more about the impact of millimetre spectrum over vehicular communication and the benefits of wider spectrum in this paper.

As more number of features are to be accessed using the vehicular communication, a variety of compact and powerful antennas are required. This article provides a complete overview of the various antennas that can be used to accommodate all the needs and features of vehicular communication. The rest of the paper is organized as follows. Vehicular network architecture (VNA) is illustrated in 1.1 and a brief description of vehicular communication applications (VCA) in 1.2. Importance of communication and how it is evolved are described in Chap. 2. Existing proposals are illustrated in Chap. 3. Fractal geometry and types of fractal antennas with various designs are discussed in Chap. 4, and finally concluding remarks are provided in Chap. 5.

1.1 Vehicular Network Architecture (VNA)

The type of communication referred to vehicular networks is entitled as vehicle-to-everything communication which is sub-categorized as (i) vehicle-to-vehicle (V2V) communication which is ad hoc and the communication can be established in two ways depending on the range of communication between the two vehicles as shown in Fig. 1. Multi-hop communication comes to existence when the vehicles are not in the range [5]. Most of the time this is useful at parking lots where the empty space can be detected way before the vehicle enter the parking area. (ii) Vehicle-to-network (V2N) communication is used for transferring the data towards the cloud, fog and grid networks as shown in Fig. 2. This type of communication basically needs infrastructure where the nearest roadside units can be connected using hotspots and the data can be transferred to a cloud [6]. Few more communications are possible such as vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I) and vehicle-to-device (V2D) in vehicle-to-everything communication.

Establishing these many varieties of communication, a powerful system architecture of the vehicular network is required which must provide in-vehicle domain, ad hoc domain and infrastructure domain components [7].

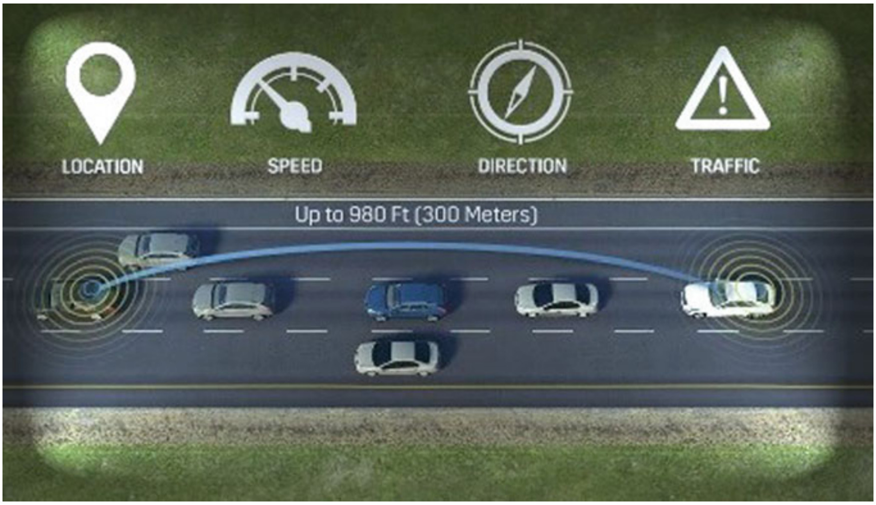

Fig. 1 Vehicle-to-vehicle communication [3]

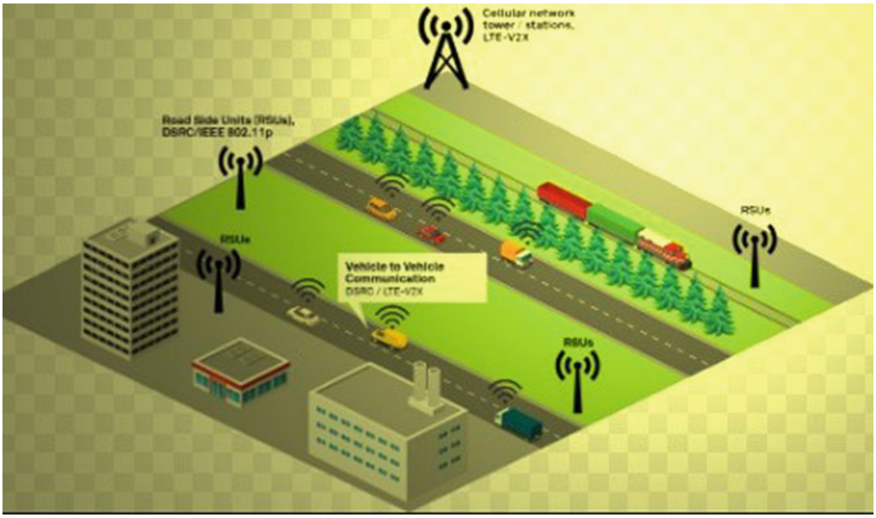

Fig. 2 Vehicle-to-network communication [5]

In-vehicle domain [8] is used for information of the vehicle like the fuel consumption, temperature in the vehicle, opening and closing of the sunroof using voice control, etc., and these can be achieved using human–machine interface along with microcontrollers in a controller area network (CAN) [9]. Different wireless technologies such as Bluetooth, Wi-Fi and GPS [10] are used to achieve the in-vehicle domain as shown in Fig. 3.

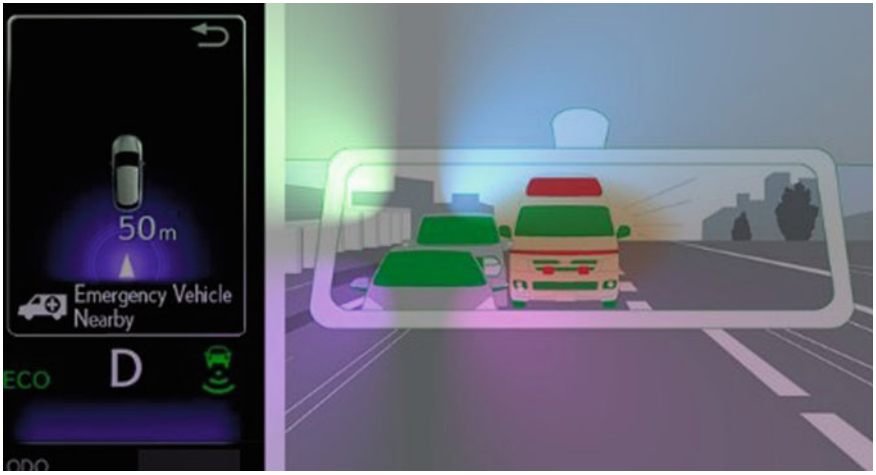

Fig. 3 In-vehicle domain [3]

Ad hoc domain is used to connect V2V as the connection must be established spontaneously and sometimes multi-hop is needed as discussed earlier. A controller can be helpful to extend the range of the communication usually called as communication controller unit (CCU) [11].

Infrastructure domain is a combination of wireless and wire communication where the roadside wireless devices can connect with the infrastructure which is a wired connection basically to provide a wireless hotspot using switches and routers as shown in Fig. 4. The wired connection is helpful to connect the authorities for collecting the information and controlling the access.

1.2 Vehicular Communication Applications (VCA)

There are numerous applications using the vehicular technology in order to provide safety, comfort, security and free flow moment. These applications can be accessed using either a sequential programming or event-driven programming. They can be categorized using the concepts like driver driven, vehicle driven, passenger driven and infrastructure driven [7]. According to the above features, these applications can be broadly classified into safety and non-safety applications. Safety applications are those applications which are directly related to the vehicles on the road [1]. It can be an information provided to the driver about the road surface ahead, or may be weather status, or may be the traffic ahead or may be road maintenance ahead or accident prone areas, pedestrian crossing ahead or any mishap occurs ahead, etc. As an example in the month of December, in Delhi a thick fog blocks the view of the driver due to which every year many vehicles collide and accidents

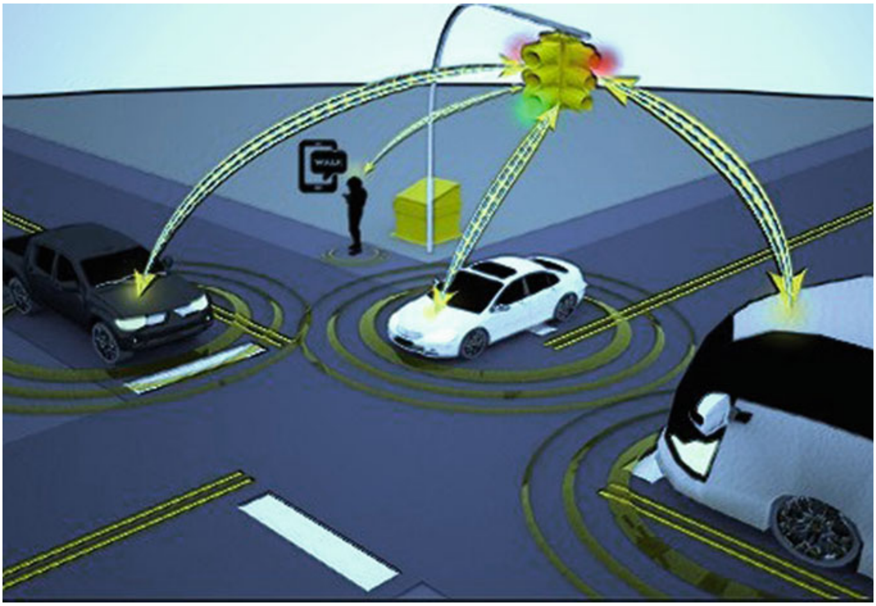

Fig. 4 Vehicle-to-infrastructure communication [3]

occur too frequently as shown in Fig. 5. Using the vehicular application, a warning message can be broadcasted which can be received by all the vehicles which are in that area such that the drivers can be more cautious and can avoid the collision. Non-safety applications are those applications which are used to provide services

Fig. 5 Accidents due to thick fog [6]

related to repairs, maintenance information [1], fuel refill stations, motels nearby [12], route guidance, navigation, etc. Now we will quickly access the history of communication and how 5G can make an impact towards the VCAs. Communication between vehicles can be ad hoc as specified by the author [11].

2 Communications

From 1980s, a rapid growth is observed in radio technologies because of multi-directional evolution with the launch of analogue cellular systems, which is considered as the first-generation cellular systems. As the second generation evolved, wireless technology came to existence. The wireless technology advanced to digital from the analogue world. This era of digital wireless communication systems consistently fulfills the growing needs of human beings for 2G to now 5G, where each generation is defined as a set of telephone network standards, which detailed the technological implementation of particular mobile system [13].

The major aim of wireless communication is to provide high quality and reliable communication [14], and each generation represented a big step in that direction. Each generation has requirements that specify things like throughput, delay, etc. that need to be considered [15].

Up to 4G, the improvement observed in the means of data capacity standard, multiplexing techniques, switching types, services, handoff types and frequency ranges.

As 5G technology evolved, which is driven by OFDM [16] as shown in Fig. 6, whose frequency band is in between 3 and 300 GHz with a mobility of 500 kbps and a latency of less than 1 ms is used. Many 5G networks are operated on high frequencies

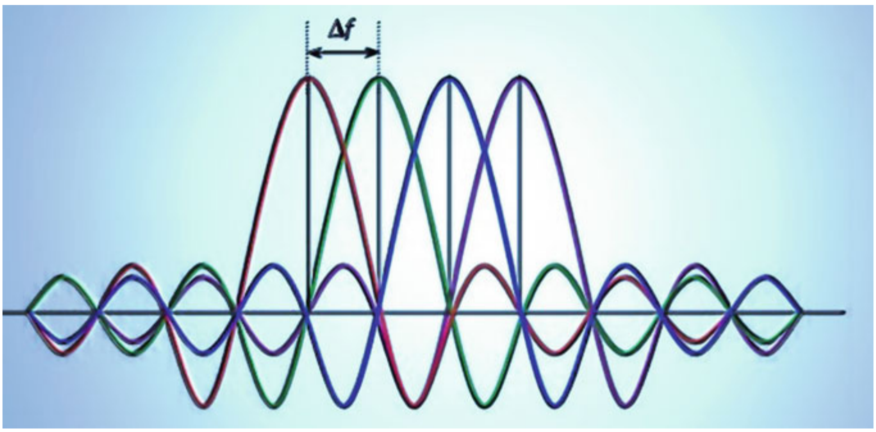

Fig. 6 OFDM [17]

called as mm waves which have the benefit to carry lots of data but are limited in the range [17]. The main drawback is that they are easily blocked by common objects.

Millimetre-wave (mm-wave) frequency ranges from 30 to 300 GHz which is much higher than the spectrum used presently in vehicular communication. If this spectrum is used wisely with better modulation and using various coding schemes with the help of beam forming, multiple-input–multiple-output techniques and using fractal geometry lead to high data rate, reduce interference and spectral reusability. IEEE 802.11ad [8] is used for the mm-wave architecture at 60 GHz frequency band over short distances ranging of 10 m. Millimetre-wave technology is also used for the automotive radar systems which are used at a high frequency of around 70 GHz and above [4]. Radar systems are used for increasing the range of communication with vehicle-to-everything communication. In order to accommodate these many various communication systems, the various authors proposed a dedicated spectrum for millimetre wave [15], which can include roadside communication, infrastructure communication, signal processing and trans-receivers in vehicles [18].

International Telecommunications Union provides the radio spectrum usage [19] for the worldwide use in which some portion of spectrum is provided for the mobile communication. At present, 3G and 4G communications are used around the world wide which is concentrating now on the next generation which is expected to standardize by the year 2020. According to the international treaty, every four years the spectrum is revised and resolutions will be carried out for the frequency band for the future use [7]. 5G network technically must have capabilities of supporting multitasking, multi-application and service provider for different networks. The bit rate must be around 20 Gbps with the mobility support up to 500 km/h with a frequency band of 700 MHz to 100 GHz [4]. The major challenges according to the author, frequent beam formation needed to track vehicles and must maintain beam alignment with low latency.

As Internet of things has an impact towards the latest technology, even Internet of vehicles as shown in Fig. 7 will establish an impact with the mm-wave communication and the frequency standards used. The communication data and the vehicles information will be sent to the cloud in order to share and access the information, which as vehicles are increasing the information, data volume will be huge and continuously increasing which must be preserved in a separate cloud for vehicle communication. The information from vehicles will be transferred to the nearest transceiver which is referred to as EDGE. The data will be transferred to a fog [9] which in turn transfers to the cloud. Using EDGE, the vehicles can offload the data, through which the latency can be minimized, in turn improves faster access and helps to enhance safety and convenience.

Fog can be used as a middle level between the cloud and edge, to facilitate faster data transfer from the end user and to minimize the latency, to improve response time and can be used to route data to the cloud.

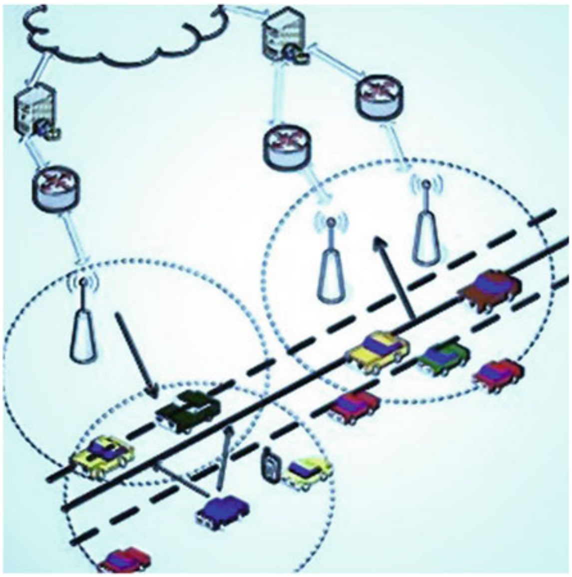

Fig. 7 Internet of vehicles [10]

3 Existing Proposals

Many authors proposed various antenna designs for the 5G communications [4, 15, 18], and hence, we can discuss a little about these antennas that can be used for vehicular communications. The first antenna in this category is a conformal antenna which can be designed on the surface of a carrier, which is helpful for saving the space and there is no damage on the mechanical structure [12]. The conformal antenna can be a micro-strip, strip line or crack antenna. The shape of this antenna is cylindrical, which is helpful to maintain a proper angle between the main lobe and the plane of array. This antenna can be used for frequency of 35 GHz, and the results are suited for vehicular communication as shown in Fig. 8. With the addition of conformal antenna, bandwidth achieved was greater than 10%, and the gain was more than 10 dB, and the first side lobe level was reduced to −16 dB. At very high frequencies, the major problem that can be seen is the uncontrolled radiation pattern. For vehicular communication, the pattern must be as directional as possible. In order to achieve as well-controlled radiation patter, the author [2] proposed switching of polarization among linear and orthogonal circularly polarized states using magneto-electric dipole antenna. This method can be used for the future antenna designs for the mm-wave communication. When this type of dipole antenna with a micro-strip line is used, there is a possibility of high mutual coupling. To achieve a low mutual coupling, the author [9] proposed insertion of rectangular slot along with the folded micro-strip line, by this way low mutual coupling can be achieved.

As for the vehicular applications are concerned, ultra-wideband antennas are majorly used which are achieved using a 2 × 2 MIMO pattern as proposed [12] and

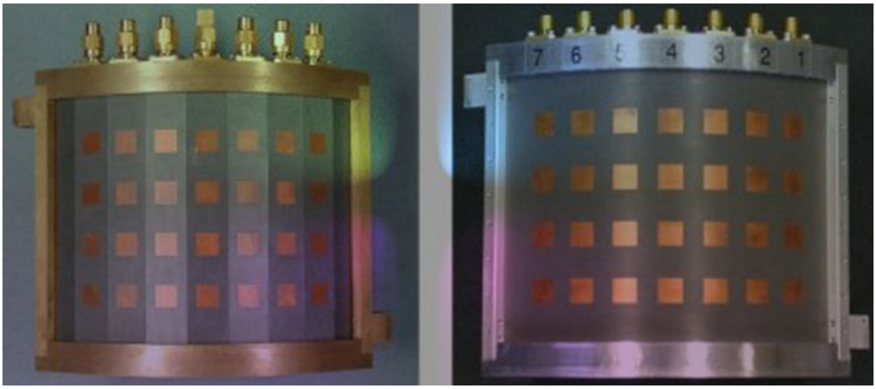

Fig. 8 Conformal antenna [20]

as shown in Fig. 9. As the frequency is increased, the bandwidth must be improved, in order to improve it a recessed ground plane is used [7]. For antenna arrays with different impedance characteristics, the author suggested an epsilon-near-zero impedance matching circuit [4], for impedances of 50, 100 and 150 Ω.

When a number of radiators are increased for arrays, there is a possibility of cross-polarization current on the radiators and low port isolation, which can be eliminated using dual-polarized antenna using vector synthetic mechanism, which has inherent advantages of high port isolation and low cross-polarization. When accessing many papers, we came across an interesting antenna which is operated in 5G bands. The

Fig. 9 MIMO antenna [12]

structure consists of hexagonal split-ring resonator (SRR) and a closed ring resonator (CRR). The proposed antenna [4] was modelled upon 0.254 mm thick Rogers substrate and has a low profile of 6×8 mm^2. It has a peak gain of 4.63 dbi with more than 80% radiation efficiency throughout its operating range. The proposed antenna has 2.83 GHz bandwidth and 7.92 GHz at 38 GHz, respectively.

For digital beam forming, a 64-channel massive multiple-input, multiple-output trans-receiver antenna was proposed [8] which consist of 16 columns and 4 rows with half-wavelength element spacing that is provided.

The next important aspect is the size of the antenna, as a number of radiators are increased the size automatically increased. One of the remedies is to use an antenna with a staircase type to reduce the overall size, and the author named it as zeroth-order resonance antenna [21]. To increase more directivity, an antenna was proposed with eight elements with very less envelope correlation coefficient [15] which is helpful for isolation. Wherever the antenna design is discussed, for better bandwidth and multi-band application, fractal antenna comes to existence. Let us discuss now the fractal antenna and how it can be significant in vehicular communications.

4 Fractal Antennas

Researchers found interesting about the fractal geometry implementing on antenna design which majorly concentrated on two areas in which the first area deals with design and analysis of the fractal antenna elements [22], and the second area is about the application of fractal concepts on designing of the array antennas. The fractal antenna possesses recursive nature which leads to develop rapid beam forming algorithms [23].

One of the major usages of fractal antenna is for ultra-wideband technology applications like imaging system, vehicular radar applications and measurement systems. New designs emerged for fractal geometry for various applications [20] and their designs can have an impact on 5G in near future.

The basic fractal models [24] were analysed for various applications at different frequencies which have no much effect on improving neither the bandwidth nor the gain, so the basic models need to be modified in order to achieve greater results.

For good impedance matching and constant gain, a new design was proposed [25] which is used for the frequency range of 3.1–10.6 GHz and the design was studied for current distribution, radiation pattern and group delay and the results were satisfactory, but still the enhancement can be done.

The enhancement can be carried out in two ways in which one of the idea is to add more antennas as the concept of arrays [18], or use of fractal layers [25] are used. In the second method is to use one fractal antenna with two separate layers [17] such that the size of the antenna need not be compromised. The increase in antenna elements can also provide significant amount of improvement as artistic array antennas. These antennas can be significant while using for wearable on-body applications [22] and vehicular communication applications. In the present scenario, fractal antennas can be most effectively used for vehicular-to-everything communication. Researchers can progress using the fractal antennas for various applications in 5G communication.

5 Conclusion

This paper provides a complete review of vehicular communication systems. We highlighted various types of communications available in the vehicular architecture. We presented the details such as in-vehicle domain, ad hoc domain and infrastructure domain. We discussed the safety and non-safety applications and the impact on the environment. We also highlighted the antennas used for 5G and the remedies provided by various authors on the problems faced in 5G communications. Finally, we discussed the novelty of fractal antennas and the impact on the future applications. We hope that this review article provides meaningful insight and leads towards the research on fractal antennas for the vehicular communication applications.

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