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Vehicular Ad-hoc Networks –Architecture, Characteristics, Research Issues, Technologies and Applications

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Abstract: Vehicular Ad Hoc Networks is a class of special wireless ad-hoc network with the characteristics of high node mobility and fast topology changes. It is one of the most interesting research areas due to low cost, flexibility, standardization, fault tolerance, high sensing fidelity, creating many new and exciting application areas for remote sensing. It has remarkable potential to improve vehicle and road safety, crash avoidance to Internet access and multimedia, traffic competence and ease as well as comfort to both drivers and passengers. It provides wide variety of services, ranging from safety-related warning systems to improved navigation mechanisms as well as information and entertainment applications. Vehicular networks will not only provide safety and lifesaving applications, but they will become a powerful communication tool for their users. So lot of research work is being conducted to study the problems related to the vehicular communications including network architecture, protocols, routing algorithms, as well as security issues. VANETs comprise vehicle-to-vehicle and vehicle-to-infrastructure communications based on wireless local area network technologies. The distinctive set of candidate applications, resources, and the environment make the VANET a unique area of wireless communication. Due to their unique characteristics such as high dynamic topology and predictable mobility, VANETs attract so much attention of both academia and industry. In this paper, we provide an overview of the main aspects of VANETs from a research perspective. This paper starts with the basic architecture of networks, then discusses research issues , and ends up with the analysis on challenges and applications of VANETs.
Keywords: vehicular ad-hoc networks, wireless ad-hoc networks, vehicular communications, dynamic topology*, Mobility, *ad hoc network, broadcasting, FCC, mobility, QoS, topology, VANET, Vehicles, Network, DSRC, ETC, RSU.

I. INTRODUCTION

VANETs which use vehicles as mobile nodes are a subclass of mobile ad hoc networks (MANETs) to provide communications among nearby vehicles and between vehicles and nearby roadside equipment [1] but differ from other networks by their characteristics. The nodes (vehicles) in VANETs are limited to road topology while moving, if the road information is available, we are able to predict the future position of a vehicle; vehicles can afford significant computing, communication, and sensing capabilities as well as providing continuous transmission power among themselves to support these functions[2].VANET applications enable vehicles to connect to the Internet to obtain real time news, traffic, and weather reports. VANETs also increase opportunities in online vehicle entertainments such as gaming and file sharing via the Internet or the local ad hoc networks.

Applications such as safety messaging are near-space applications, where vehicles in close
proximity, exchange status information to increase safety awareness. The aim is to enhance safety by alerting emergency conditions. Applications for VANETs are mainly oriented to safety issues (e.g., traffic services, alarm and warning messaging, audio / video streaming and generalized infotainment, in order to improve the quality of transportation through time-critical safety and traffic management applications). At the same time, also entertainment applications are increasing (e.g., video streaming and video-on demand, web browsing and Internet access to passengers to enjoy the trip).

V2V communications have the following advantages: (i) to allow short and medium range communications, (ii) to present lower deployment costs, (iii) to support short messages delivery, and (iv) to minimize latency in the communication link. Vehicle-to-Vehicle(V2V) communications present the following shortcomings that can be solved with the integration with Vehicle-to-Infra structurte(V2I), such as (i) frequent topology partitioning due to high mobility, (ii) problems in long range communications, (iii) problems using traditional routing protocols, and (iv) broadcast storm problems [3] in high density scenarios. On the other hand, the strong points of V2I, are the following: (a) information dissemination for VANETs, especially using advanced antennas [4], (b) VANET / Cellular interoperability [5], and (c) WiMAX (Worldwide Interoperability for Microwave Access) penetration in vehicular scenarios [6]. The integration of WiMAX and WiFi technologies seems to be a feasible option for better and cheaper wireless coverage extension in vehicular networks.

Vehicular Ad-hoc Networks can be viewed as component of the [7] Intelligent Transportation Systems (ITS). Figure 1consists of vehicles and roadside base stations that exchange primarily safety messages to give the drivers the time to react to life-endangering events.

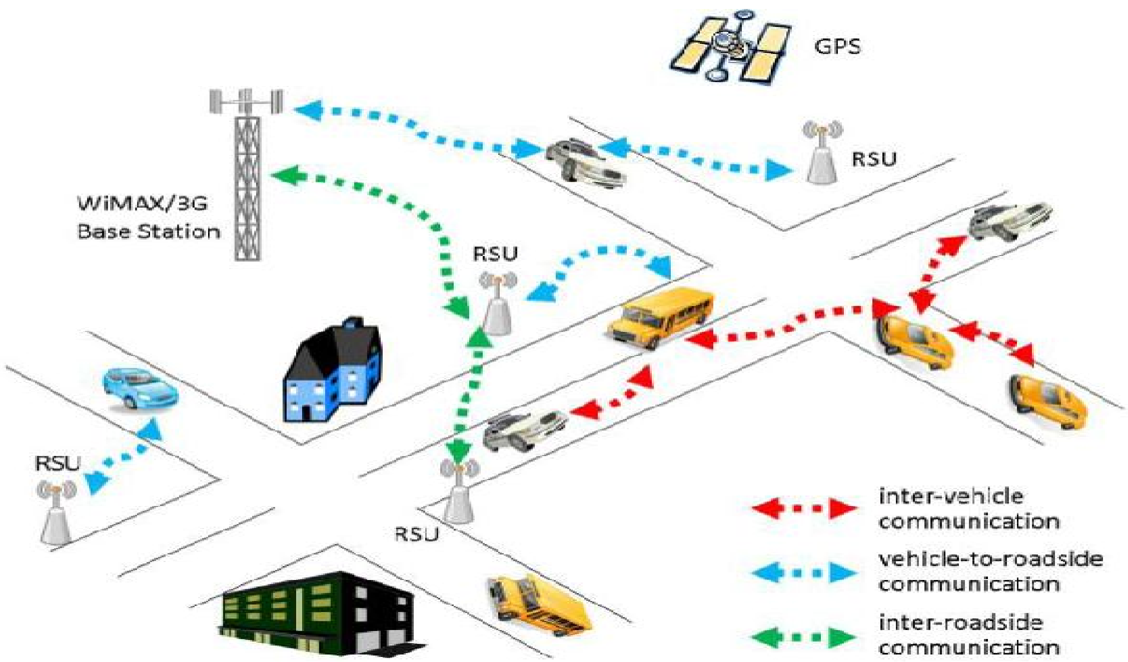

Figure 1. VANET

A. Network Architectures And Characteristics

MANETs generally do not rely on fixed infrastructure for communication and dissemination of information. VANETs follow the same principle and apply it to the highly dynamic environment of surface transportation.

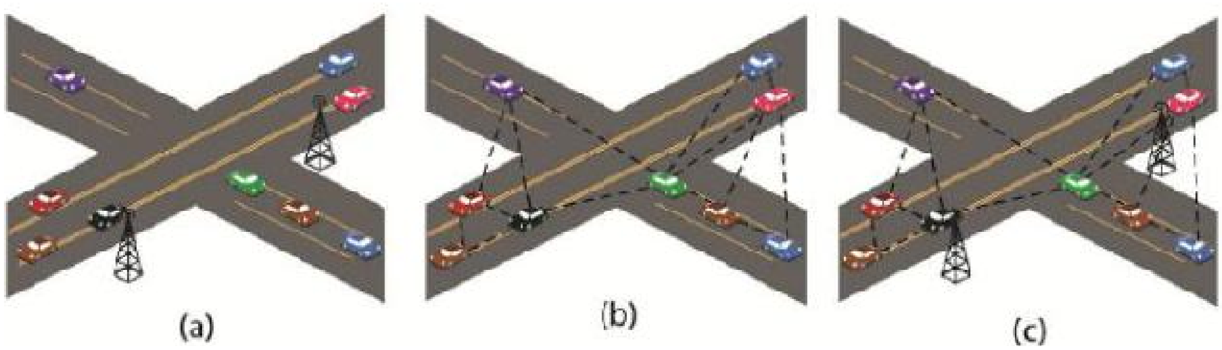

Figure 2:Three possible network architectures for VANETs.

As shown in Figure 2, the architecture of VANETs falls within three categories: pure cellular/WLAN, pure ad-hoc, and hybrid. VANETs may use fixed cellular gateways and WLAN access points at traffic intersections to connect to the Internet, gather traffic information or for routing purposes. The network architecture is a pure cellular or WLAN structure as shown in Figure 2(a). VANETs can combine both cellular network and WLAN to form the networks so that a WLAN is used where an access point is available and a 3G connection otherwise. Stationary or fixed gateways around the sides of roads provide connectivity to mobile nodes [8] but are not feasible considering the infrastructure costs. In such a scenario, all vehicles and roadside wireless devices can form a mobile ad-hoc network (Figure 2(b)) to perform vehicle-to-vehicle communications(V2V)and achieve certain goals, such as blind crossing (a crossing without light control). Hybrid architecture (Figure 2(c)) of combining cellular, WLAN and ad-hoc networks together has been a possible solution for VANETs. Namboodiri *et al.* [9] proposed such a hybrid architecture which uses

some vehicles with both WLAN and cellular capabilities as the gateways and mobile network routers so that vehicles with WLAN capability can communicate with them through multi-hop links to remain connected to the world. VANETs comprise of radio-enabled vehicles which act as mobile nodes as well as routers for other nodes.
The unique characteristics of VANET include:

B. *Predictable mobility*

Unlike MANETs, the network nodes (here vehicles) of VANET move in a predefined way because road layouts are fixed and vehicles have to obey and follow road signs, traffic signals, as well as respond to other moving vehicles [10].

C. *High mobility and rapid changing topology*

Vehicles move fast especially on roads and highways. Thus, they remain within the communication range of each other for a very short time, and links are established and broken fast which results to rapid changes in network topology [11]. Moreover, driver behavior is affected by the necessity to react to the data received from the network, which causes changes in the network topology [10]. The rapid changes in network topology affect the network diameter to be small, while many paths may be disconnected before they can be used.

D. *Geographic position available*

Vehicles can be equipped with modern, accurate positioning systems integrated by electronic maps. For example, global positioning system (GPS) receivers are very popular in cars which help to provide location information for routing purposes [11].

E. *Variable network density*

The network density in VANET varies depending on the traffic load, which can be very high in the case of a traffic jam, or very low, as in suburban areas [10].

F. *High computational ability*

As vehicles are nodes in VANET, they can hold a sufficient number of sensors and enough communication equipment such as high speed processors, large memory size, advanced antenna technology and modern GPS. These resources increase the computational power of the node, which help to create reliable wireless communication and to collect accurate information of node's current position, speed and direction [10].

G. *Research Issues*

VANETs introduce a new challenging environment for developers and communication engineers. There are many different hot topics to be studied by researchers as follows:

1) *Mobility Modeling:* Traditional ad-hoc networks assume limited node mobility, where nodes are usually handheld devices like laptops, PDAs, smart cell phones, etc. For VANETs, mobility is typical, and is measured in miles. There is a strong relationship among vehicles mobility pattern on the same road as they travel by following the same traffic rules and regulations. Further, since two vehicles remain within their communication range for a matter of seconds, it is an open research issue to develop rich topology model [12] for VANET that will differ from traditional network topologies which require significant interaction between the sender and receiver.
2) *Routing protocols:* Routing plays an important role in VANET applications but the traditional network routing protocols are not appropriate with this vehicular environment as the vehicles move in high-speed resulting rapid change in network topology and not to establish end-to-end connectivity between source and destination nodes [13]. This has prompted researchers and developers to establish rich and robust routing algorithms to deal with the VANET environment that will provide high throughput and better packet delivery ratio.
3) *Scalability issues:* One of the main challenges inherent to the deployment of VANETs is operability, both in very light and in highly overloaded networks [14]. It is always expected that VANET must work in low density areas such as roads and highways, as well as in situations with high traffic density areas, such as cities, urban areas where traffic jams are high and major intersections exist on road. The number of active nodes (vehicles) and scalable protocol design may be a great issue both for researchers and developers.

4) *Security frameworks:* Vehicular networks rely on distributed non trustworthy nodes which should cooperate with each other . Security issues are a major concern in the VANET environment as nodes communicate with each other through wireless communication. Any change in the network information by a fraud node may cause great harm for the vehicle drivers and passengers, as well as partition the network and decrease the performance of the whole network. So it can be an essential research issue to develop a robust security [15] solution for the VANET network that will meet the diverse needs of the applications reliably with minimum involvement of un-trusted nodes.
5) *Quality of Service (QoS):* QoS support over VANETs remains a challenge when current routing paths become no longer available as a result of changes in node velocity, node positioning, network topology or distance between vehicular nodes [16]. It may be a challenging issue both for network engineers and researchers to utilize the available bandwidth allocated for VANET to improve delivery of messages as well as to develop adaptive QoS routing protocols that will establish new routes quickly and efficiently.
6) *Broadcasting:* Broadcasting continues to be a strong research area of focus by VANET researchers because a significant number of messages transmitted in VANETs are broadcast messages [16]. Effective and co-operative broadcasting algorithms are of concern for the researchers and developers to circulate safety and routing information both in the low density car areas and in the congested city areas where large number of private cars are plying on.

II. TECHNOLOGIES

Several technologies are involved in Vehicular Ad hoc Networks, especially as enablers of Intelligent Transportation Systems (ITS). These are GSM, UMTS, Wi-MAX limited Wi-Fi and a new and specific technology thought for this kind of applications, namely Wireless Access in Vehicular Environments (WAVE), also known as IEEE 802.11/*p* [17]. This implicitly suggests that a car should have on board different radio interfaces (and/or network card). About WAVE, it is member of the IEEE 802.11 family, this implicitly suggests that this solution (currently at the stage of draft) is borrowed from IEEE 802.11 and adapted for the vehicular context. Recent advances in the area of ITS have developed the novel Dedicated Short Range Communication (DSRC) protocol, which is designed to support high speed, low latency V2V, and V2I communications, using the IEEE 802.11*p* and WAVE standards.

The allocated frequency and newly developed services enable vehicles and roadside beacons to form VANETs in which the nodes can communicate wirelessly without central access point.

The first channel is for V2V communication with public safety purposes while the second and third channels are private channels and used for public safety too in a medium range environment. The fourth is a control channel while the fifth and sixth channels are for public safety services with short range. The seventh channel is dedicated to manage public safety intersections.

The worldwide ISO TC204 / WG16 has produced a series of draft standards, known as CALM (Continuous Air-Interface, Long and Medium Range). The main goal of CALM is to develop a standardized networking terminal, able to connect vehicles and roadside systems, avoiding disconnections. This can be accomplished through the use of a wide range of communication devices and networks, such as mobile terminals, wireless local area networks, and the short-range microwave (DSRC) or infrared (IR).

The CALM architecture separates service provision from medium provision via an IPv6 networking layer, with media handover, and will support services using 2G, 3G, 5 GHz, 60GHz, IEEE 802.16*e*, IEEE 802.20, etc. A standardized set of air interface protocol is provided for the best use of resources available for short, medium and long-range, safety critical communications, using one or more media, with multipoint transfer.

The CALM concept is at the core of several major EU sixth framework research and development projects. In the United States, the Vehicle Infrastructure Integration (VII) initiative will be operating using IEEE 802.11*p* / 1609 standards at 5.9 GHz, which are expected to be aligned with CALM 5.9-GHz standards, although the IEEE standards do not have media handover.

Due to the recent strides made in VANETs, a new class of in-car entertainment systems and enabling emergency services using opportunistic spectrum has increased by means of Cognitive Radio (CR) technology [15]. These CR-enabled Vehicles (CRVs) have the ability to use additional spectrum opportunities outside the IEEE 802.11*p* specified standard band.

The growing spectrum-scarcity problem, due to the request of high-bandwidth multimedia applications (*e.g.*, video streaming) for in-car entertainment, and for driver-support services, such as multimedia-enabled assistance, has driven researchers to use the CR technology, for opportunistic spectrum use, which directly benefits various forms of vehicular communication.

In such a network, each CRV implements spectrum management functionalities to (*i*)detect spectrum opportunities over digital television frequency bands in the Ultra-High

Frequency (UHF) range, (*ii*) decide the channel to use based on the QoS requests of the applications, and (*iii*) transmit on it, but without causing any harmful interference to the licensed owners of the spectrum.

The CRV network can also leverage the constrained nature of motion, *i.e.* along linear and

Pre decided paths corresponding to streets and freeways. At busy hours or in urban areas, spectrum information can be exchanged over multiple cooperating vehicles, leading to know more about the spectrum availability.

This also allows the vehicles that follow to adapt their operations and undertake a proactive response, which is infeasible in static and non-stationary scenarios with random motion.

The CRV networks fall under three broad classes, such as (*i*) V2V only, (*ii*) V2I only, and (*iii*) centralized V2I. In the first class, a network can be formed between vehicles only that rely on cooperation for increasing accuracy. The second class deals with interactions between vehicles and roadside BSs, where the latter acts as a repository of data that is used by passing vehicles. Finally, a completely centralized network is possible, in which the BS decides the channels to be used by the CRVs, without relying on information from the vehicles.

The access problem can be solved on two different layers. The first access problem is the selection of the network providing the service. The second one is the access within the selected network. This is true for the V2I environment. Once specified the network quality metric, the vehicle should select the best network (this is the principle of *vertical handover*).

Regarding the V2V communications, requiring network synchronization appears complicated so static access procedure x-DMA usage is discouraged. Dynamic access best suits the typical channel features of the multi-hop network so Carrier Sensing Multiple Access –Collision Avoidance may be used. In this context the lack of synchronization at network level is not dramatic and requires only a node-by-node synchronization.

Regarding V2V connections some routing *philosophies* can be considered. These are Geo-Broadcast, when a node send to all its neighbors an update about a region, Geo-any cast when a vehicle interrogates other nodes about road status and Fleet net Routing, when a Greedy approach is used, that is, each node tries to forward the information according to a metric (variation of flooding) and it can be implemented via a beacon-based scheme that requires each node to periodically transmit its position. It this last the positioning is really important and it can be derived or via an absolute service —like GPS— or by triangulation, so requiring

more signaling. The use of GPS (and, more in general, the GNSS) unit within the vehicles allows knowing the vehicles' positions. The awareness of precise locations is important to every vehicle in VANET so that it can provide accurate data to its neighbors. Currently, typical localization techniques integrate GPS (GNSS) receiver data and measurements of the vehicle's motion.

III. APPLICATIONS

Vehicular applications are typically classified in (i) active road safety applications, (ii) traffic efficiency and management applications, and (iii) comfort and infotainment applications [18]. The first category aims to avoid the risk of car accidents and make safer driving by distributing information about hazards and obstacles. The basic idea is to broaden the driver's range of perception, allowing him/her to react much quicker, thanks to alerts reception through wireless communications. The second category focus on optimizing flows of vehicles by reducing travel time and avoiding traffic jam situations. Applications like enhanced route guidance/navigation, traffic light optimal scheduling, and lane merging assistance, are intended to optimize routes, while also providing a reduction of gas emissions and fuel consumption.

Some of the most requested applications by polls, currently under investigation by several car manufacturers are Post Crash Notification (PCN), Congestion Road Notification (CRN), Lane

Change Assistance (LCA) and Cooperative Collision Warning (CCW). In the following, a brief overview of the above-cited applications is provided.

In PCN, a vehicle involved in an accident would broadcast warning messages about its position to trailing vehicles so that it can take decision with time as well as to the highway patrol for asking support. The PCN application may be implemented both on V2V and V2I network configurations. In fact the V2V presents the advantage of giving quickly the information through a *discover-and-share* policy. Through the use of specific sensors, it consists in measuring possible changes in the behavior of the driver (*e.g.*, quick brake use, rapid direction changes, and so on), which are then communicated back through directional antennas to the other vehicles along the same direction. Once received, the closest vehicle can share this information with the other nodes with a flooding routing. In the particular case of false alarm by the first vehicle experiencing the irrational behavior of the driver, this information floods on the VANET. It is then important to fix the issue of false alarms.

Let us suppose a driver has been distracted by something and moves the steering wheel, so that the vehicle direction changes accidentally. Once recognized the error, the driver will react by quickly changing direction or with a quick and strong use of breaks.

This behavior is not rational since there is no danger for the VANET community, but only the behavior of a single is irrational. This represents a false indication of alarm. If the first following driver does not experience some accidents, then the vehicle does not forward this information, and false alarm probability is reduced, otherwise if it discovers the same problem, it shares such information with the other vehicles.

Dealing with the use of V2I architecture, the access points should gather information (*e.g.*, alarms for quick speed changes), coming from different vehicles, and merging the data so reducing the signaling from the vehicles. The V2V has the drawback of not allowing a quick communication if the vehicles are far away from each other (*e.g.*, in low traffic density scenarios), while the V2I is more energy consuming since it should be on all the time.

The LCA application constantly monitors the area behind the car when passing or changing lanes, and warns the driver about vehicles approaching from the rear or in the next lane over.

This application has two different modalities, the first one is called passive mode, while the other one is the active mode. In the passive mode the vehicle simply measures distances, by means of detection and ranging procedures, while in the active mode it communicates to the other vehicles that they are too close, so they should change their direction / behavior.

Traffic monitoring and management are essential to maximize road capacity and avoid traffic congestion. Crossing intersections in city streets can be tricky and dangerous at times. Traffic light scheduling can facilitate drivers to cross intersections. Allowing a smooth flow of traffic can greatly increase vehicle throughput and reduce travel time [19]. A token-based intersection traffic management scheme is presented in [18], in which each vehicle waits for a token before entering an intersection. On the other hand, with knowledge of traffic conditions, drivers can optimize their driving routes, whereby the problem of (highway) traffic congestion can be lessened [20].

CRN detects and notifies about road congestions, which can be used for route and trip planning. This kind of application is partially implemented in current GPS-based applications where a new route is evaluated when heavy congestion has been detected on a route or in a portion of it. Up till now several commercial tools are available for smart-phones and special purpose devices. These are currently based on GPS coordinates and local resident software

Smart Vehicles, able to indicate the shortest or fastest routes from a starting point till a destination by considering one ways streets and so forth. A new generation of this kind of software integrates some control messages coming from the so-called Radio Data System-Traffic Message Channel(RDS-TMC) that gathers information about unavailable routes or congested streets.

A. Electronic brake lights, which allow a driver (or an autonomous car or truck) to react to vehicles braking even though they might be obscured (e.g., by other vehicles).
B. Platooning, which allows vehicles to closely (down to a few inches) follow a leading vehicle by wirelessly receiving acceleration and steering information, thus forming electronically coupled "road trains".
C. Traffic information systems, which use VANET communication to provide up-to-the minute obstacle reports to a vehicle's satellite navigation system
D. Road Transportation Emergency Services, where VANET communications, VANET networks, and road safety warning and status information dissemination are used to reduce delays and speed up emergency rescue operations to save the lives of those injured.
E. On-The-Road Services, it is also envisioned that future transportation highway would be one that is "information-driven" and "wirelessly-enabled". When one drives on the road, VANETs can help the driver to discover services (shops, gas stations, etc) on that street, and even be notified of any sale going on at that moment. Drivers can also book a cinema ticket while driving their way to the cinemas.
F. *Electronic Toll Collections (ETCs):* Each vehicle can pay the toll electronically when it passes through a Toll Collection Point (a special RSU) without stopping. The Toll Collection Point will scan the Electrical License Plate at the OBU (on-board unit) of the vehicle and issue a receipt message to the vehicle including the amount of the toll, the time and the location of the Toll Collection Point. In the MAC layer, the Electronic Toll Collections priority. It should be a direct one-hop wireless link between the Toll Collection Point and the vehicle
G. *DAHNI (Driver Ad Hoc Networking Infrastructure):* DAHNI provides numerous possibilities to revolutionize the automotive and transportation industry of the future. For example, data captured by DAHNI, when properly aggregated, can be fed into the traffic monitoring and flow control system for real-time traffic management. Alternatively, such information can be archived for off-line analysis to understand traffic bottlenecks and devise techniques to alleviate traffic congestion.

*H. Dedicated Short-Range Communications (DSRC) :*DSRC system has emerged in North America, where 75 MHz of spectrum was approved by the U.S. FCC (Federal Communication Commission) in 2003 for such type of communication that mainly targets vehicular networks. On the other hand, the Car-to-Car Communication Consortium[4] (C2C-CC) has been initiated in Europe by car manufacturers and automotive OEMs (original equipment manufacturers), with the main objective of increasing road traffic safety and efficiency by means of inter vehicle communication. IEEE is also advancing within the IEEE 1609 family of standards for wireless access in vehicular environments (WAVE).

IV. CONCLUSION

In this paper, we first introduce the VANETs architecture. Then we discuss VANETs research issues as well as applications. This paper introduces the vehicular ad hoc networks from the research perspective, covers basic architecture, critical research issues, and general research methods of VANETs, and provides a comprehensive reference on vehicular ad hoc networks. VANET is a promising wireless communication technology for improving highway safety and information services. Many VANET applications do not use traditional forms of communication, but require broadcast communication and more advanced information dissemination schemes. The prospective applications of Vehicular ad-hoc networks (VANET) are categorized in to three major groups as comfort oriented applications, convenience-oriented applications and safety oriented applications. Safety oriented related applications look for the increasing safety of passengers by exchanging relevant information via vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). Moreover, VANETs differ notably from other types of ad-hoc networks, such as wireless sensor networks or mobile ad-hoc networks, because of node heterogeneity and dynamics. There are a number of contributions that produced significant results, but the general feeling is that the subject is not still mature, and that a lot of work remains to be done. It is expected that this paper will help students, developers and researchers to address the challenges involved in VANET.

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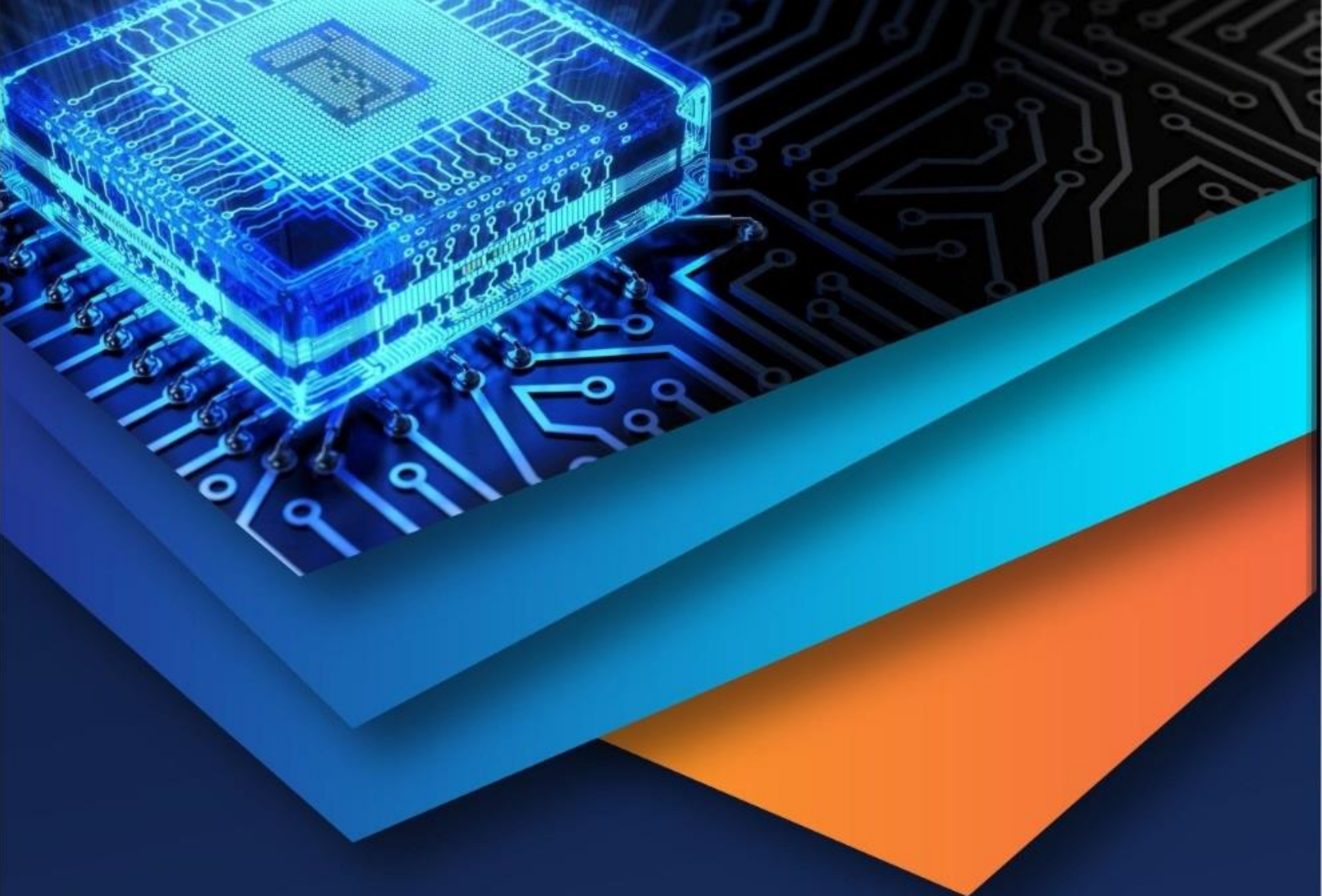

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