Review On Vertical Handover Techniques in VANET: Algorithms, Input Parameters, and Evaluation Metrics

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***Abstract*— Vertical Handover Techniques (VHOs) allow mobile devices that support multiple wireless technologies to switch from one wireless network to another by promising to maintain a seamless connection in highly dynamic scenarios such as in-vehicle networks (VNs). Persistent connectivity is a serious problem caused by the extremely dynamic network topology and the highly variable number of nodes being moved. In addition, the efficiency of traffic and the effectiveness of the dissemination of road safety messages is a serious problem. Recently, heterogeneous cellular networks with DSRC for the automotive network have been proposed and have attracted a lot of attention. The consolidation offers many possible advantages, such as high data rates, low latency, and extended communication range. In a heterogeneous wireless environment, a smooth handover decision is required to ensure the QoS of communication and maintenance of continuous connection between mobile nodes. This article reviews some relevant studies (algorithms, input parameters, and evaluation metrics) in the literature dealing with VANETs and other heterogeneous wireless communication networks in terms of vertical handover technology. In addition, this work**

will aid future researchers in gaining insight into the collaboration of vehicular heterogeneous networks (especially DSRC and Cellular Networks) in constructing VANETs and improving driver safety.

KEYWORDS

Vertical Handover, Heterogeneous Vehicular Communication, DSRC, Cellular Networks

Introduction

The growing communication infrastructure allows connections through a variety of wired and wireless technologies in different settings. The adoption of wireless technology is growing at a very rapid rate. This trend is essentially due to reasons such as (i) the miniaturization of devices such as laptops, and netbooks, (ii) the multiple networking interfaces available in most devices, and (iii) the availability of several wireless technologies such as Wireless Fidelity (Wi-Fi), Worldwide interoperability for Microwave Access (WiMAX), and Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE) and 5G. The need to integrate different wireless network technologies to provide "seamless" interoperability, integration, and convergence between these heterogeneous technologies necessitates the use of Vertical Handoff (VHO) technology.

Handover, also known as handoff, is an event that occurs whenever a mobile node moves from one radio cell to another, giving up its connection with the first base station and connecting to the second base station. When a handover occurs within the realm of a single radio access technology, the process is called horizontal handover. On the other hand, vertical handover is a term meaning handover between heterogeneous radio access network technologies. Fig. 1 shows both horizontal and vertical handover events. Handoff technology has been extensively studied in cellular communications and is gaining attraction in IP-based wireless networks [1]. A handover is considered 'smooth' when all applications running on the mobile device can keep the connection alive, providing continuous end-to-end data service within the same session during the switchover, providing both low latency and minimal packets. Loss.

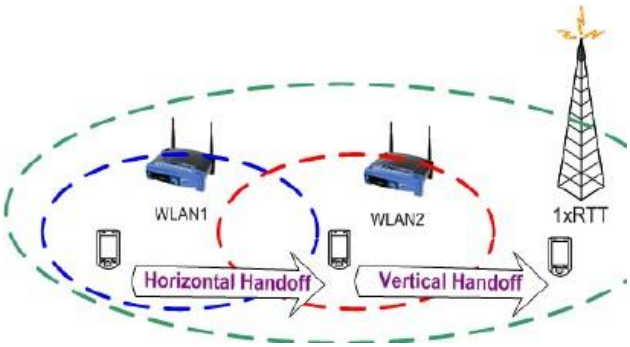

Fig. 1: Illustration of the horizontal and vertical handover processes

The research community is putting considerable effort into the convergence of various wireless networking technologies. Because of this, there are various proposals covering heterogeneous scenarios, protocols, handover techniques and algorithms, network technologies, metrics, and procedures. In addition, the IEEE 802.21 working group, which aims to provide a homogeneous functional interface between heterogeneous network technologies, has been working on the Media Independent Handover Services Protocol, [2] since 2004 to provide standard handover services between lower and upper layers. In November 2008, the IEEE 802.21 standard was finally approved. Nevertheless, there have been proposals and studies to improve and solve the performance of 802.21 in terms of VHO efficiency. [3], [4], [5].

Regarding standards, VHO techniques, algorithms, input parameters, and evaluation metrics, this review intends to review the most important proposals found in the literature. It also highlights the VHO process from a heterogeneous vehicle network (VN) perspective, highlighting techniques and algorithms that are better suited for this type of network. As most of the proposals in the literature merely consider specific VHO techniques for heterogeneous vehicle networks this review paper may be useful for this purpose.

2. Vehicular Networks

Every year, millions of people die in road traffic accidents around the world. About 1.25 million people die each year as a result of road traffic accidents (3400 deaths per day) [6] according to the World Health Organization (WHO) review on road traffic injuries (May 9, 2016). Furthermore, forecasts predict worse conditions by 2020 and estimate that road traffic accidents will increase to become the seventh leading cause of death [7]. Preventing these accidents by Clearly articulating this prediction has been a challenge. Urgent action and focused efforts are required to prevent and reduce vehicle accidents and improve road safety.

Intelligent Transportation Systems (ITS) have recently attracted academia and industry to save lives, money, time, and the environment. Japan and Sweden have publicly announced the goal of a zero-traffic fatality society by 2020 and beyond, hoping for such technologies (ITS) [8]. The Intelligent Transportation Association (ITSA)'s "Vision Zero" manifesto summarizes its mission to minimize fatal accidents and delays [9]. With the recent development of the automobile and wireless communication technology, the development of ITS solves many vehicle traffic problems, such as information dissemination and traffic congestion. One component of ITS for mobile vehicle connectivity and wireless communications is the Vehicle Ad-hoc Network (VANET). Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications in VANET are inherently enabled by wireless communication technologies. A process by which vehicles can communicate with each other and exchange information about their status (e.g. position, speed, acceleration, etc.) or traffic information (e.g. traffic light status, accidents, traffic jams, a line running, etc.) is called V2V communication.

V2I communication refers to the collaboration between road infrastructure and automobiles in a similar operation. VANETs handle both safety-critical applications and non-safety infotainment or entertainment-based applications. Safety applications such as collision avoidance, pre-crash awareness, or lane change are used to reduce road accidents by employing traffic monitoring and management apps. Non-safety applications are used to allow passengers to access various services such as interactive communication, internet access, payment services, online games, and information updates while cars are in motion.

The IEEE 802.11p standard [10, 11, 12] is an update to the well-known IEEE 802.11 standard that is based on considerable VANET research. The upgraded version of IEEE 802.11p is the standard for Wireless Access in Vehicular Environments (WAVE) with a frequency of 5.9 GHz. The WAVE protocols (IEEE 802.11p/1609) enables interoperability between wireless devices on-board units (OBU) of cars and infrastructure located near the roadside unit (RSU). Thus, V2V and V2I connections may be formed in the vehicular network. Despite the substantial study, IEEE 802.11p suffers from scalability concerns, restricted coverage areas, and unbounded delays.

Cellular networks, on the other hand, have recently been incorporated. Due to several difficulties associated with IEEE 802.11p, researchers have been driven to study the feasibility of utilizing cellular networks in-vehicle applications instead of IEEE 802.11p. By comparing the features of various access methods, it is established that the cellular network is the best alternative to IEEE 802.11p for supporting vehicle applications. LTE's distinctive properties are fast data rates, good spectral efficiency, and reduced control plane latency [13]. Existing radio access networks, such as cellular networks (3G/LTE/5G) and Wi-Fi, may be used to improve vehicular communications and guarantee cars have access to the network even when RSUs are not present. The potential impact of heterogeneous wireless networks has proven that the ever-increasing volume of mobile internet traffic cannot be absorbed entirely by cellular data communication networks. A heterogeneous vehicular network can be formed by combining VANETs with cellular networks for automotive communications.

When migrating between heterogeneous networks, flawless handover is the initial step. It is more critical to initiate vertical handover for convenience reasons than for connection purposes (e.g., according to user choice for a specific service). Vertical handover management has two significant challenges: seamlessness and automation in network switching. The growing relevance of interconnectivity across VANETs has been acknowledged by major automobile manufacturers, governmental bodies, and the academic community [14]. Many government initiatives have been carried out in the United States, Japan, and the European Union. The Federal Communications Commission has awarded spectrum to Inter-Vehicle Communications (IVC) and comparable applications [15].

Governments and well-known industrial companies such as Toyota, BMW, and DaimlerChrysler have initiated important projects for IVC communications. The following are several noteworthy projects from the Japan Automotive Research Institute (JSK) that are an important step towards realizing intelligent transportation services; Advanced Driver Assistance Systems (ADASE2) [16], Collision Avoidance Metrics Partnership (CAMP) [17], Chauffeur in EU [18], CarTALK2000 [19], FleetNet [20], California Partners for Advanced Transit and Highways (California PATH) [21], and DEMO 2000.
In recent years, few studies have investigated heterogeneous vehicle communication. An overview of a single network or ITS is the focus of these existing investigations [13], [22, 23, 24, 25, 26]. Wu et al. [27] address the challenge of using dedicated short-range communications (DSRC) for vehicle communication and proposed solutions. [28] provided a comprehensive overview of automotive ad hoc networks. Problems and solutions to connected vehicles were discussed by the authors in [29]. Each system offers its unique advantages, so heterogeneity between different networks is important [30]. Viriyasitavat et al. [31] analyzed the appropriate channel and propagation models for this heterogeneous system because the automotive network environment is very dynamic. Various automotive applications have also been considered in some studies[32, 33, 34]. Furthermore, the ability of LTE to support vehicular applications is briefly evaluated in [13]. On the other hand, the coverage problem in VANETs [35] is proposed as a solution together with the Worldwide Interoperability for Microwave Access (WiMAX) network. Studies in [13] and [23] focus on the use of LTE in vehicular networks over heterogeneous wireless networks.
3GPP LTE and IEEE 802.11p/WAVE technologies were compared by Vinel et al to determine which technologies can support collaborative media security applications [23]. Basic techniques and principles of Internet access in VANETInternet integration scenarios have been studied by Mane & Junnarkar in [36]. To prioritize the dissemination of urgent messages, they worked to improve the performance of mobile gateways and data collection. Furthermore, V2I communication over heterogeneous multilayers with multiple Radio Access Technology (RAT) network environments is reviewed in [24]. The various VANET technologies in the survey were presented by Shahid et al. in [37]; while for vehicle safety at intersections, UMTS and LTE were compared in [38]. In addition, Mir et al. compared a hybrid communication system between LTE and WAVE protocols [39]. In contrast, for heterogeneous vehicle communications, a combination of both LTE and 802.11p as a hybrid approach has been proposed in [40]. Collaborative efforts have been suggested in [41, 42, 43] different LTE-VANETs. DSRC for V2V communication and LTE for V2I communication is one of the best solutions to support vehicular services in the heterogeneous vehicular network as concluded in a study [44] by Zheng et al.

For our study, we present a review of vertical handoff techniques in the heterogeneous vehicular communications environment. Along with existing surveys in the literature, this current article focuses on comparing the different solutions provided by the VANET research community for vertical handover looking at the algorithms, input parameters, and

Evaluation metrics used. Metrics such as bandwidth, throughput, latency, communication overhead, channel capacity, and packet loss are the comparisons on which different operations are based. Many challenges must be addressed to make the vehicle communication idea a commercially sustainable reality for 5G networks and autonomous vehicles. This work will motivate VANET researchers, automakers, and new entrants to develop VANET heterogeneous wireless network integration technologies.

The rest of this paper is structured as follows. VANET architecture and background are discussed in Section 2. Wireless access standards in VANET are discussed in Section 3. VANET characteristics are briefly described in Section 4. Section 5 discusses heterogeneous vehicular communications possible scenarios. Section 6 discusses the various vertical handover stages, the Input Parameters, Evaluation Metrics, Algorithms, and Approaches used for Vertical Handover in literature.

2. VANET: Architecture

The special network in which the devices that make up the network is known as the Vehicle Adhoc Network (VANET). VANET is not the same as Intelligent Transportation System (ITS). All types of communication inside a vehicle, between vehicles, or with a road unit are under ITS. ITS is not only limited to road transport but also includes rail, maritime, and air transport. This means that VANET is a subset of ITS. As shown in Fig.2, there are three types of domains in the architecture of the VANET communication system: the in-vehicle domain, the ad-hoc domain, and the infrastructure domain.

2.1. In-Vehicle Domain

An onboard unit (OBU) and one or more application units (AU) are included in this domain. A single OBU can be integrated into multiple AUs; between them can be wired or wirelessly connected. The communication links between V2I and V2V are ensured by an OBU. Then, a single network device based on IEEE 802.11p radio technology is installed on an OBU.

2.2. Ad-hoc Domain

Vehicles prepared with OBUs and stations through the roadside, i.e. Road Side Units (RSUs) incorporate the Ad-hoc Domain. An RSU may be visible as a static node whilst an OBU may be visible as a movable node of an ad-hoc community. A gateway is required to connect the RSU to the World Wide Web. Directly or through multi-hops RSUs can talk with each other. Providing internet connectivity to the OBUs is the primary goal of the RSU. It also forms a mobile ad-hoc network that allows OBUs to communicate between vehicles without the need for centralized coordination. [45].

2.3. Infrastructural Domain

To access the infrastructure, the network RSU can connect the OBU to the Internet as shown in Fig. 2. This allows the AU through the OBU to connect to any Internet-based host. For non-safety applications, the OBU can also communicate with other hosts using cellular radio network communications (GSM, GPRS, UMTS, HSDPA, WiMAX, and 4G).

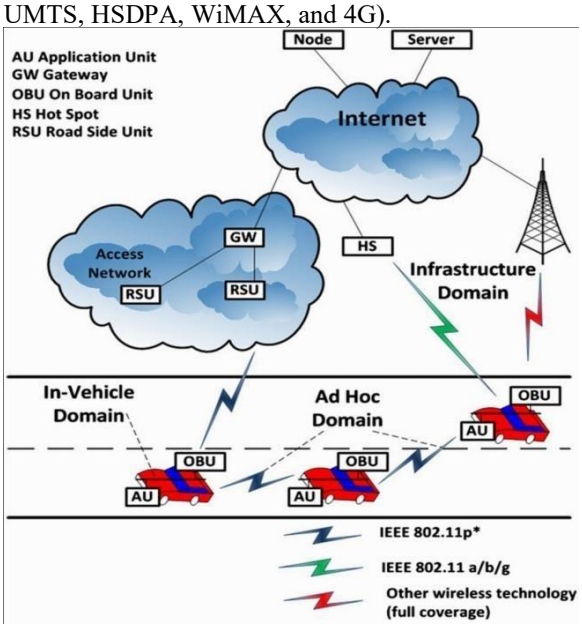

Fig. 2. The architecture of the VANET communication system.

The specific constituents of VANET are an application unit, an onboard unit, and a roadside unit. The architecture given below gives a momentary description.

A. On-Board Units (OBUs)

In addition, a vehicle using a permanently installed OBU exchanges information with the RSU or with other OBUs. For use in short-range wireless communication based on IEEE 802.11p radio technology, the OBU includes a resource control processor (RCP), a user interface, and a dedicated interface for connecting to other OBUs and network equipment. Additionally, for non-safety applications based on other radio technologies such as IEEE 802.11a/b/g/n, it may include an additional network device. Through a wireless link based on the IEEE 802.11p radio frequency channel, the OBU is

Responsible for communicating and connecting with the RSU or other OBUs. Wireless radio access, network congestion control, ad-hoc and geo-routing, reliable messaging, data security, and IP mobility are key roles of the OBU.

B. Application Units (AUs)

An integrated entity called the Application Unit (AU) works with the OBU and shares OBU processing and wireless resources. Similarly, multiple AUs can work with a single OBU and assume similar responsibilities. To manage all network utilities and mobility, the AU interacts exclusively through the OBU [45]. To connect to the OBU, the AU and OBU connections can be wired or wireless to the OBU in a single physical unit. In addition, for all mobility and network functions, the AU communicates with the network via the OBU.

C. Road-Side Units (RSUs)

The devices that are placed at static locations along roads and highways or specific locations such as intersections, near parking lots, hospitals, shopping malls, restaurants, etc. are referred to as a Road-Side Unit (RSU). They are composed of at least a network device based on IEEE 802.11p. The main function of the RSUs is to provide internet connectivity to the OBUs. A group of sensors with an OBU fitted on the vehicle will collect the information and send it to other vehicles or the RSU via wireless channels. As a bridge, RSU also connects multiple AUs of vehicles to the Internet [46]. The primary functions and procedures according to the Car 2 Car Communication Consortium [47], concerning RSUs are [28]:

- To redistribute the information to other OBUs and other RSUs to forward it to other OBUs by this there is an extension of the ad hoc network.
- To use V2I communication to run safety applications such as a low bridge warning, accident warning, or work zone, and also act as an information source.
- To provide the OBUs with an internet connection.

Allowing communication among nearby vehicles, between vehicles, and fixed roadside units is the main goal of the VANET architecture. This is shown in the following three categories as shown in Fig. 3.

a. Vehicle-to-Vehicle (V2V) Communication

V2V communication allows direct vehicular communication without depending on fixed infrastructure support. This is also referred to as inter-vehicle communication. Safety, security, and dissemination applications are primarily featured in V2V. Moreover, for V2V communication, to expand the users' perceptual horizon the vehicles exchange data which can describe the vehicles' internal states and environment. In this way, any important information collected from the sensors on a vehicle may be sent to its neighbouring vehicles. Therefore, to prevent fatal road accidents V2V communication is necessary. It is mostly present in the form of automotive lighting, such as turn signals and brake lights.

b. Vehicle-to-Infrastructure (V2I) Communication

Communication between a vehicle and the roadside Infrastructure is responsible for the V2I communication for information and data-gathering applications. Cellular gateways and wireless space networks have used the vehicles. V2I communication for safety purposes is defined by the United States Department of Transportation (US DoT) as the wireless exchange of critical safety and operational data between vehicles and roadway infrastructure, intended primarily to avoid motor vehicle boom [48]. Providing information and entertainment services to drivers and passengers are the extra features that can benefit from the wireless exchange of data. Automotive information and entertainment services can be, current weather forecasts, traffic information, online gaming, music, and video streaming. To alter the duration of traffic light phases or to report traffic situations and the internal state of the vehicle, the vehicles can interact with infrastructure. For routing purposes, a VANET roadside infrastructure can be used.

c. Hybrid Architecture (V2X)

The working together of V2V and V2I communications in VANET form a hybrid architecture. For example, a vehicle can communicate with the roadside infrastructure and share the data received from the infrastructure with other vehicles. Two types of communications are available in the adhoc domain according to [49, 50, 51]. Vehicles can communicate directly with another vehicle if there exists a direct wireless connection available between them this is known as a single hop V2V communication on the other hand the condition exists differently when there is no direct connection between them. A dedicated routing protocol is used to forward data from one vehicle to another until it reaches the destination point this is also known as multi-hop V2V communication. The vehicles can also communicate.

With the RSU, the range of communication by receiving, sending, and forwarding data from one node to another V2I communication.

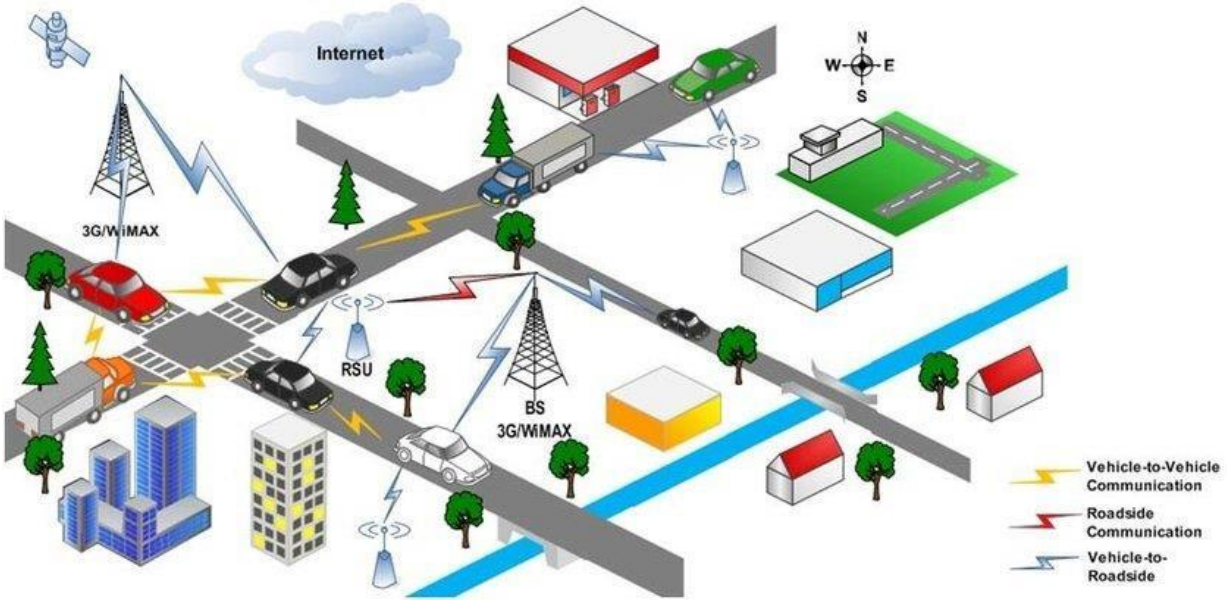

Fig. 3. Communication in VANET

3. Wireless Access Standards in VANET

Many technologies are utilized in VANET, including Dedicated Short-Range Communication (DSRC) and Wireless Access in Vehicular Environment (WAVE).

3.1. Dedicated Short-Range Communication (DSRC)

The United States Federal Communication Commission (FCC) assigned 75 MHz of the dedicated short-range communication (DSRC) spectrum at 5.9 GHz between 5.850 and 5.925 GHz for ITS in 1999 [52], [53] In 2008, the European Telecommunications Standards Institute (ETSI) granted 70 MHz of spectrum in the 5.8 GHz range [54] for DSRC applications. The ISO Communication Access for Land Mobiles (CALM) began DSRC standardization in 2001, and the IEEE 802.11p was concluded in 2010 [55]. In this day and age, the DSRC has emerged as the appropriate standard for V2V and V2I communications. The DSRC communication range is
300 meters to one kilometre, allowing for high-speed communication between automobiles and roadside infrastructure as well as between vehicles. It can withstand speeds of up to 200 km/h. Half-duplex with a transfer rate of 6-27 Mbps is the standard. The Orthogonal Frequency Division Multiplexing (OFDM) technology is supported by DSRC for data multiplexing. The OFDM approach divides the input data stream into parallel bitstreams and transfers the individual bitstreams onto overlapping subcarriers.

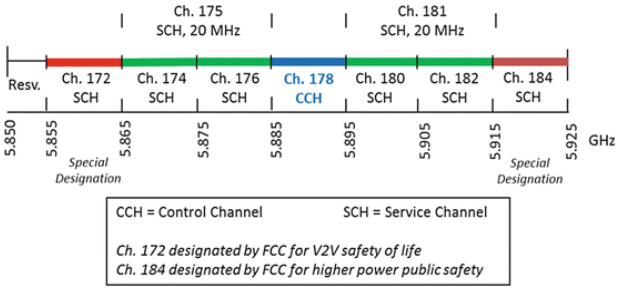

Fig. 4. DSRC spectrum is allocated by the FCC

The DSRC spectrum is divided into seven channels, as seen in Fig. 4 and 5, starting with channel number 172 and concluding with channel number 184. The spectrum consists of a 5 MHz guard band, one 10 MHz Control Channel (CCH), and six 10 MHz Service Channels (SCHs). Channel 178, the control channel (CCH), is used only for safety communications. Furthermore, channels 172 and 184 are allocated for safety purposes, while the remaining service channels are utilized for both safety and non-safety applications (SCH). According to the ETSI institute [56], the entire spectrum in DSRC is divided into time slots of 50 ms, with messages having two different priorities: low for data dissemination messages delivered in the SCH channels, and high for safety or control signals transmitted in the CCH channel. When the CCH channel is active, all nodes must cease communicating during the CCH time frame to receive and deliver security messages.

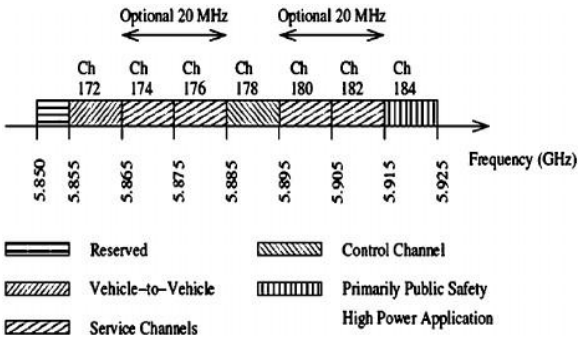

Fig. 5. Multi-channel operation in a vehicle network that complies with the IEEE802.11p European standard.

3.2. IEEE 1609-Standards for Wireless Access in Vehicular Environments (WAVE)

Wireless Access for Vehicular Environments is another name for IEEE 802.11p (WAVE). WAVE is an IEEE 802.11 standard modification. The WAVE standard is necessary for ITS applications in short-range communications. High-speed data transport and communication are essential due to the high topological change and mobility of Vehicular nodes. As a result, the ASTM 2313 working group rebranded DSRC to IEEE 802.11p WAVE [57]. This is possible on both the MAC and physical layers. WAVE includes the Road Side Unit (RSU) and On-Board Unit (OBU). WAVE uses the 5.850-5.925 GHz frequency spectrum for V2V and V2I communications. Using real-time traffic analytics can help enhance VANET performance. WAVE uses OFDM techniques to split the signals into different narrowband channels.

4. Characteristics of the VANET

The notion of vehicular ad-hoc networks (VANETs) evolved from mobile ad-hoc networks (MANETs). They share traits such as low bandwidth, short radio transmission range, self-organization, self-management, and omnidirectional broadcast. VANETs have various characteristics that set them apart from traditional mobile Adhoc networks.

VANETs have the following distinguishing features:

- *Highly dynamic mobility and topology:* A vehicular network is deemed highly dynamic due to the speed of the vehicles and radio propagation characteristics. As a result, automobiles travel at speeds ranging from 50 km/h in urban areas to more than 100 km/h on highways [58]. The dynamic nature of the vehicular network causes them to swiftly join or exit the network, resulting in irregular and rapid topology changes.

- *Network topology evolves quickly:* VANET nodes are known for their high speed. Vehicles on the road change their position and speed often, causing the network topology to vary rapidly. The duration of the link between vehicles is affected by the radio communication range and vehicle direction. Cars travelling in opposing directions may have a relatively short lifespan link, whereas vehicles travelling in the same direction may experience frequent link ruptures and more packet loss, resulting in lower throughput. When the link connection fluctuates rapidly and many pathways are severed before being used, the effective network diameter shrinks [59].

- *Low link availability (often disconnected):* When the network topology is very dynamic, with high-speed vehicular nodes and limited transmission range, the link between two cars can abruptly evaporate while transferring information. As a result, vehicles travelling in opposing directions and vehicles travelling in the same direction at high speeds may have low link availability.

- *Variable network density:* The network density in VANET fluctuates depending on the time and the network area. In suburban traffic, network density can be relatively low, while in a metropolitan traffic bottleneck, it can be very high. During rush hour, there is a lot of traffic, however, it is normally light in rural areas [60], [54].

- *No power constraints:* In the VANET, power is not a major issue because cars can deliver continuous power to the OBU due to their long battery life. In the case of mobile ad-hoc networks, this is not the case. [60, 61, 62].

- *Restricted and predictable mobility:* In-vehicle ad-hoc networks, nodes do not move at random; instead, they follow lanes and itineraries, which is not the case in mobile ad-hoc networks. Given the vehicle's mobility pattern, which is normally confined by roads, streets, highways, traffic signals, speed limits, and traffic conditions, it is more feasible to anticipate the vehicle's future position.

- *Huge-scale network::* Dense urban regions, such as city centres, major city entrances, and highways, may have large networks [60], [54]. As a result, identifying the intended receiver before data distribution becomes a major difficulty because VANET may encompass numerous towns or cities.

- *Hard delay limitations and real-time needs:* VANET protocols must meet the requirements of applications. Safety messages are the prime purpose of VANETs.

As a result, safety messages must be specified of top importance and delivered on time.

- *Geographical communication:* Where cars can be accessed is determined by their geographic position. The situation is different in other networks where an ID or a group ID defines the target vehicle or a group of target cars.

- *Urban versus Rural:* Vehicle density varies across time and place, which is a significant difficulty. In rural locations, network dispersion and increased interference, respectively, make V2V communication difficult and contribute to shadowing and fading in urban circumstances.

- *Propagation model:* VANETs can operate in three different environments: highway, rural, and urban. In a highway, the propagation model is usually believed to be free space. The signal is reflected in the signal by the wall panels around the roads, causing interference. Because of the varying vehicular density and the existence of buildings, trees, and other objects that interfere with signal propagation, the surroundings in a city make communication problematic. The impacts of such opposition include shadowing, multipath, and fading. The propagation model is generally believed not to be free-space due to the features of the communication environment. Due to the various topography shapes, it is critical to address signal reflection and attenuation during signal propagation (fields, hills, climbs, dense forests, etc.). As a result, the free-space paradigm is inappropriate in this case. The impacts of potential wireless communication interference from other vehicles and networks must be included in the VANET propagation model.

- *High computational ability:* VANET nodes can be supplied with a sufficient number of sensors and computing resources, such as CPUs and big memory capacity, to boost their computational capability. This will aid in the establishment of secure wireless communication. Furthermore, these resources will be quite useful in obtaining correct information about the current node position, speed, and direction [62].

- *Network administration:* VANET functions in a dispersed form because there is no centralized administrative entity. When there is no central administrator, nodes are given additional duties.

5. Scenarios of Heterogeneous Vehicular Communication

Many wireless communication methods have been considered to support ITS services. It is difficult to provide good ITS services just through a single wireless network due to the constant topology changes of VANETs and significant mobility. Furthermore, the authors [63] demonstrated that DSRC performs poorly with a large number of cars. Similarly, as the number of vehicles on the road grows, LTE networks become readily overburdened. As a result, integrating several wireless access networks such as DSRC and LTE as a heterogeneous vehicular network seems promising to meet several criteria of ITS services. Various wireless access technologies can be used to facilitate V2I and V2V communications. As a result, selecting the most appropriate and efficient technology for a Vehicular User (VU) that matches the QoS metrics is difficult. Zheng et al. [44]. proposed a new layer called the Heterogeneous Link Layer (HLL). The HLL runs on top of the MAC layer in each radio access network, providing a consistent interface to the higher layers. This new layer may be able to meet the QoS requirements by facilitating cooperation between multiple radio networks.

5.1. V2V Communication

As discussed in Section 2, V2V communication provides direct vehicular communication without relying on permanent infrastructure assistance. In this part, we look at two potential V2V communication mechanisms.

5.1.1. DSRC

The DSRC technology is appropriate for both safety and non-safety services in V2V communications. V2V communications based on DSRC do not conflict with cellular networks because they use distinct frequency bands. Using DSRC in V2V communications, however, poses significant difficulties [26], [64]. Because of the CSMA mechanism's limitations, collisions occur often in densely crowded traffic situations.

5.1.2. LTE D2D

Device-to-Device (D2D) communication is the method by which User Equipment (UE) can communicate directly with each other [65]. As a prospective solution for V2V, D2D communications in LTE confront some obstacles [66], [67]. To begin with, interference is a big worry when using D2D in a heterogeneous vehicle context. In addition, unlike medium or high-speed vehicles, most D2D devices in LTE networks are usually immobile or have low-speed mobility. As a result, D2D communication performance may suffer. Furthermore, due to the existing peer and service discovery of D2D communications, it is not well suited for vehicular.

Contexts. Finally, requesting D2D discovery is a time-consuming task. As a result, the D2D discovery time may be longer than the message transmission time in some circumstances. Due to the tight latency requirements of safety applications, this is not appropriate for transmitting safety notifications.

5.2. Communication of V2I

V2I communication allows a vehicle to communicate with roadside infrastructure to obtain information and data. V2I communication is commonly proposed to be supported by cellular networks. However, another option is to use DSRC in V2I.

5.2.1. DSRC

The IEEE 1609 working group for DSRC networks has created a set of standards to fulfil the needs of vehicular communications. In addition, the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) method has been modified to meet the MAC layer's QoS criteria [68]. Many broadcast protocols for DSRC safety broadcast services have been proposed in the literature [69, 70, 71, 72, 73, 74]. As a result, when using DSRC networks for V2I communications, various issues must be solved.

5.2.2. Cellular networks

In cellular networks, two transmission modes can be used for V2I communications: unicast and multicast/broadcast. Unicast is a point-to-point communication protocol between a vehicle and a base station that can be used for both uplink and downlink message distribution.
Multicast/broadcast, on the other hand, is a point-to-multipoint transmission that is used to disseminate downlink messages. On the one hand, V2I communication can be accomplished using the Wideband Code Division Multiple Access (WCDMA) system. However, because the delivery latency is greater than the demand, this system cannot adequately offer safety services in vehicular communications. LTE, on the other hand, provides a fantastic platform for V2I communication. The LTE system's flat architecture is optimized for reduced transmission delay. Furthermore, the evolved Multimedia Broadcast and Multicast Service (eMBMS) is a cost-effective method of supporting multicast or broadcast services in high-density vehicle situations. LTE networks can provide high capacity and wide coverage. However, there are a few issues to address. Table 1 [7] summarizes the benefits and drawbacks of using DSRC and LTE for V2V and V2I communications. The study in [44] proposed a new layer of HLL because partnerships between heterogeneous networks are critical.

Table 1: Advantages and challenges of key candidates in heterogeneous vehicle communications based on [44].

Mode of Communication	**DSRC**		**LTE/LTE D2D**	
	Advantages	Challenges	Advantages	Challenges
Communication of V2V	-Ad-hoc mode - Small cost and easy installation - Wave Short Message (WSM) overhead is small	-Hidden mode and broadcast storm issues -Channel congestion by numerous vehicles -Sparse pilot development -Adjacent band leaks in multi-channel operation	- Spectral efficiency is High - D2D resource scheduling is Effective - Energy Efficiency in High	- High-speed vehicles degrade in performance - Between D2D pair and other users there is Interference -There is a consumption of time on Peer and service discovery
Communication of V2I	- Small cost and easy installation - local message dissemination is Suitable for i.e. parking information, traffic signals, etc.	- Hidden mode and broadcast storm issues -Channel congestion by numerous vehicles -Sparse pilot development -Unstable link -Prioritization and service selection	-Huge coverage -The capacity for both uplink and downlink is high -The operation of mobility management is tough -efficiency on eMBMS is High -The architecture is Centralized and flat	-High delays in disseminating messages caused by users in the idle state -Prone to overloaded in high-density environments -Lack of efficient scheduling schemes for ITS services

Under this new framework, several candidate technologies can collaborate. Finally, Table 1 shows that DSRC is better for V2V communications than LTE D2D. On the contrary, the LTE cellular network is the best choice for V2I communications.

6. VANET Integration with Various Heterogeneous Wireless Networks

Different radio access technologies (RATs) such as Wi-Fi, WiMAX, 3G, and 4G networks, and diverse cell formats are used in heterogeneous networks. Many researchers have investigated the vehicular networks domain in the literature [28]. However, a few recent articles [44, 75, 22, 23, 24, 25, 26] have focused on the diverse environment of vehicle communications.

The adoption of LTE in automotive networks across heterogeneous wireless networks was the focus of studies in [13] and [23]. In [23]], Vinel et al. examined 3GPP LTE and IEEE 802.11p/WAVE technologies to see whether one might provide cooperative vehicular safety applications. LTE has superior network capacity, better mobility, and greater coverage, but it suffers from higher latency and increased network stress when compared to 802.11p [76].

However, [40] presented hybrid techniques for heterogeneous vehicular communication that combine both LTE and 802.11p. In [77, 78]], various LTE-VANET cooperation were proposed. Zheng et al. found that heterogeneous vehicular networking with LTE for V2I communications and DSRC for V2V communications is one of the best methods for supporting vehicular services in their study [44]. Viriyasitavat et al. examined the optimal channel and propagation models for this heterogeneous network because the vehicular network environment is highly dynamic [31].

Several studies looked at various automobile uses [32], [33]. Similarly, [34] divides existing VANET context-aware programs into three categories: environment, system-and-application, and context-awareness. VANET makes use of a variety of wireless technologies to provide an effective, reliable, and adaptable internet access solution. In [36]], Mane and Junnarkar examined internet access methodologies and foundations in VANET-Internet integration scenarios. This project aims to improve the performance of mobile gateways and data collecting to prioritize the distribution of emergency notifications. However, Gerla et al. [79] identified the urban internet infrastructure's role in clarifying the significance of urban internet infrastructure in supporting growing vehicular applications and highlighted the mobile internet's future in vehicular networks. Furthermore, a recent study in [24] looked at V2I communication in heterogeneous multi-tier networks with a variety of radio access technology (RAT) environments. In [80] Shahid et al. published a survey of several VANET technologies, whereas in [81], a comparison of UMTS and LTE for vehicular safety communication at junctions was reported. The primary wireless technologies for heterogeneous vehicular communications are summarized in Table 3.

Mir et al. [39] also presented a hybrid communication system combining LTE and the WAVE protocol. Furthermore, some research [82], [83] has shown that satellite communication could be used in vehicle network communications. In [84], Li et al. advocated using satellite communication just in the downlink and cellular systems in the uplink. Many studies are now being conducted on seamless connectivity in heterogeneous multi-RAT environments. The majority of this research focused on achieving smooth vertical handover, data distribution, and mobility, while others concentrated on security concerns.

6.1. Vertical Handover

Service continuity, network discovery, network selection, security, device power management, and QoS issues should all be considered and addressed in an accurate VHO process [85, 86, 87], with the latter being the most important. Several approaches [88, 89, 90] divide the VHO process into three stages: (i) obtaining information, (ii) making a decision, and (iii) carrying out the choice. The relationships between the three phases necessary to achieve handover in heterogeneous networks are depicted in Fig. 6.

6.1.1 Information gathering for the handover

Not only network information is collected during the handover information collection phase, but also information about the rest of the system's components, such as network attributes, mobile devices, access points, and user preferences. As a result, this phase is referred to as handover data collection [91], system discovery [92], system detection [93], handover initiation [94, 95] or simply network discovery [96, 97, 98]. The information is collected and processed in this phase to make decisions in the handover decision phase. The following is a typical list of data collected:

- Availability of nearby network links by providing data such as speed, cost, packet loss ratio, handoff rate, Received Signal Strength (RSS), Noise Signal Ratio (NSR), Carrier Interference Ratio (CIR), Signal

Interference Ratio (SIR), and Signal to Interference Ratio (SIR)., Bit Error Ratio (BER), distance, location, and QoS factors are all variables to consider.

- The state of the mobile device is determined by gathering data on the battery, resources, speed, and service class.
- Information about the user's choices, such as budget and services required

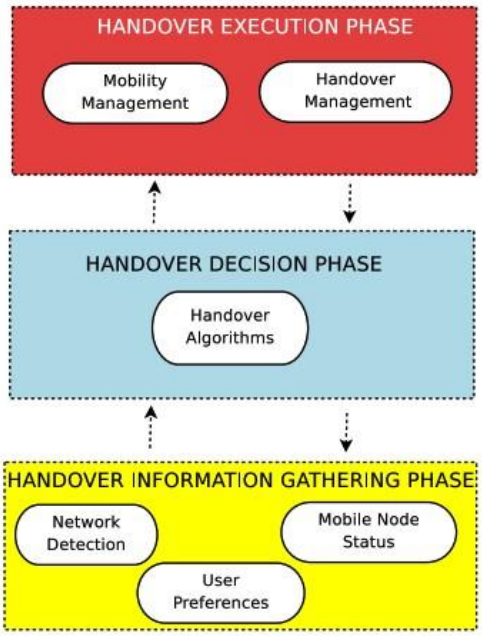

Fig. 6. Procedure for handover management

6.1.2. Decision on handover

One of the most important steps during the handover is the decision phase. System selection [89], network selection [88, 98] or handover preparation [94] are all terms used to describe this phase. This phase determines When and Where to initiate the handover based on the information gathered. The When choice refers to the precise moment in time when an ideal handover can be made, whereas the Where decision pertains to selecting the best network that meets our switching requirements. In a homogenous network environment, deciding When to hand over is normally based on RSS values, however, deciding Where to hand over is not an issue because we all utilize the same networking technology (horizontal handover). The answers to these problems are complicated in heterogeneous networks. To make the best selections, the data gathered must be analyzed using a variety of parameters obtained from various data sources, such as the network, mobile devices, and user preferences. VHAs are used to weigh and evaluate the characteristics involved in each specific requirement. Techniques such as fuzzy logic, neural networks, and pattern recognition, among others, are examples of algorithms that allow for the evaluation of cross-layer multi-parameters.

3.3. Handover execution

This phase handles the handover; in addition to handling the handover, it should also ensure a smooth session changeover. Different handover mechanisms collaborate with control signalling and IP management protocols to execute the VHO. Handover execution [92, 91, 90], is the most common name for this step, but it's also known as VHO assessment [95] or Handoff implementation [96]. The dynamic of the accessible information on the devices and the network must be considered during the data collection phase. Making decisions based on highly dynamic data when the device is mobile necessitates a fast and accurate decision system. Finally, the VHO must be properly managed to obtain accuracy by taking into account the geographical location, the chosen network, and the exact moment.

Table 2: Input Parameters and Evaluation Metrics Used for Vertical Handover

	Area	Metric	Narrative	Utilized as: Input parameter	Utilized as: Evaluation Metrics
Network	Latency	Latency e2e, Average delay	latency for End-to-end, from sending the packet to receiving a packet	[99, 100, 101, 90]	[100, 97, 101, 102, 103, 104, 105]
		Delay in Network	Amount of time to deliver a packet	[91, 101, 103, 88, 106, 107, 96, 108, 109, 110]	[87, 86, 111]
	Coverage	Network availability, coverage	the network area coverage	[97, 91, 112, 113, 114, 108, 115, 116]	
	Performance	RSS	Received signal strength	[117, 118, 90, 119, 91, 120, 121, 101, 122, 123] [124, 104, 125, 98, 126, 112, 127, 128, 129] [105, 95, 130, 131, 92, 132, 133, 134, 135, 136]	
		CIR	Carrier interference ratio	[119, 101]	
		RTT	Round trip time	[119, 90, 101, 122, 137, 106, 108, 115]	
		Retransmissions	Packets retransmitted	[101, 137]	
		BER	Bit error rate	[100, 91, 119, 101, 87, 127, 88, 107]	
		SIR	Signal-to-interference and noise ratio	[138, 87, 95, 115]	
		Security	The security of the network	[100, 101, 139]	
		Packet loss	Unsuccessful delivery of Packets	[91, 101, 103, 106, 96, 115]	[140, 106, 86, 141, 109, 111]
		Throughput, data rate	Network Throughput	[99, 142, 131, 107, 143]	[1, 138, 122, 124, 87, 104, 144, 126, 127, 137] [106, 86, 95, 145, 115]
		Bandwidth available	Available bandwidth instantaneous in the network	[90, 100, 99, 124, 146, 103, 104, 88, 119, 131] [96, 115, 109, 147]	[148, 116]
		The bandwidth offered, link capacity	The candidate network offered bandwidth	[91, 85, 103, 98, 130]	
		Network Jitter	Jitter induce by the network	[91, 101, 139, 103, 88, 106, 131, 107, 115]	[86, 111]
		Network overhead	Additional management packets in the network		[149]
	Billing	Cost/money	Network price utilization	[100, 91, 101, 139, 124, 87, 150, 103, 98, 88] [92, 143, 96]	[100, 103, 151]
	Miscellaneous	Number of users	Available users in the network	[99, 151]	
User preferences		Budget	Budget user utilization of the networks	[91, 88, 96]	
		Preferred network	User choice	[91, 97, 99, 88, 114, 96, 115]	
Mobile terminal	Location	Mobility, location	Geolocation or AP-based location	[91, 120, 122, 123, 125, 95, 114, 96, 132, 135]	
		Movement	The change in movement direction	[125, 120, 96, 132]	
		Speed, velocity	The speed while moving the mobile terminal	[91, 125, 99, 139, 104, 98, 96, 115, 147]	
		Network interfaces	Technologies available in the device	All proposals are referred	
		Battery consumption	Power consumption	[91, 99, 101, 139, 150, 98, 88, 148, 114, 96] [147]	[148]
VHO	Occurrence	Number of VHO	Events performed by VHO		[90, 125, 87, 122, 142, 123, 124, 150, 98, 112] [152, 133, 95]
		VHO success rate	The success performed ratio of VHO events	[4]	[147]
	Latency	VHO Latency	Time is taken for the VHO process		[1, 4, 126, 153, 113, 154, 132, 136, 109, 155] [156]
		Gathering latency	Time is taken for the VHO Gathering phase alone		[4, 154, 157]
		Decision latency	Time is taken for the VHO Decision phase alone		[4, 154, 157]
		Execution latency	Time is taken for the VHO execution phase alone		[4, 154, 157]
		Dwell time	Length of time the VHO process remains suspended to allow another process to run.	[119, 126, 105, 90]	
	Network	VHO packet loss	Packet delivery failure in the VHO process		[121, 97, 136]

The VHO process requires accurate data collection because the decision-making procedure is based on it. The efficiency of the VHO in terms of optimization in decision-making to connect to the optimal network can also be determined by evaluating its performance. Table 2 shows the many parameters that various authors employed in their proposals and publications. Since vehicles are continually on the move, V2I communication requires a Vertical Handover (VHO) between the vehicle and the infrastructure. However, when the frequency of handovers grows, ping-pong effects emerge. The VHO in VANET heterogeneous wireless networks has been studied in certain articles [158], [159]. In addition, the VANET multi-hop communication model presented in [160] is used in a new handover mechanism. Layer-3 latency is reduced using this approach. Chen et al. proposed a method in which a vehicle leaving the network sends its IP address information to the automobiles behind it as they enter cell coverage. A quick handover can also be done by anticipating the vehicle's movement [161]. Further enhancements to interference management have been presented in [84]. Li et al. studied uplink interference using a Coordinated Multi-Point (CoMP) method, in which user equipment in a multi-coverage area selects a cell with superior connection quality.

A moving vehicle must prioritize selecting the proper target roadside in multi-tier RAT diverse environments.

Table 3: Main wireless technologies for heterogeneous vehicular communications as adapted from [8] and [40].

Feature	**Wi-Fi**	**802.1p**	**UMTS**	**LTE**	**LTE-A**
Frequency band(s)	2.4 GHz, 5.2 GHz	5.86-5.92 GHz	700-2600 MHz	700-2690 MHz	450 MHz-4.99 GHz
Width of Channel	20 MHz	10 MHz	5 MHz	1.4, 3, 5, 10, 15, 20 MHz	Up to 100 MHz
Distance	Up to 100 m	Up to 1 Km	Up to 10 Km	Up to 30 Km	Up to 30 Km
Bit rate	6-54 Mb/s	3-27 Mb/s	2 Mb/s	Up to 300 Mb/s	Up to 1 Gb/s
Coverage	Intermittent	Intermittent	Ubiquitous	Ubiquitous	Ubiquitous
Mobility support	Low	Medium	High	Very high (up to 350 Km/h)	Very high (up to 350 Km/h
V2I support	Yes	Yes	Yes	Yes	Yes
V2V support	Ad-hoc	Ad-hoc	No	No	D2D

And not the incorrect one. Packet losses, ping-pong, and even call drops can occur in these contexts, necessitating a seamless and dependable handover [162]. However, because the performance of 802.11p may be hampered by non-line-of-sight settings, WiMAX technology was developed to allow high-speed V2I communication. With an expected handover delay of less than 30 ms, the IEEE 802.16 m WiMAX version can handle mobility up to 350 km/h [163]. In [164]], the essential phases of a VANET handoff procedure were investigated, as well as several similar research in the literature that reduces VANET handoff time. This study also looked at the rapid handoff systems provided in prior studies to improve the various phases of the handoff. However, [165] discusses the numerous handover needs as well as the essential aspects that influence the handover procedure. Several parameters related to the VHO process were also discussed. Advanced VHO decision-making approaches were investigated. RSS measurements, QoS parameters, and mobile terminal position information are all examples of metrics that might be used to trigger handover decisions. The majority of the research relies on a single-criteria decision-making system. Similarly, in [166], Midya et al. compared various VHO techniques based on criteria such as handoff latency, addressing, technology, and handoff choice.

6.1.1. Vertical handover algorithms

[148]created a VHO decision method that maximizes the aggregate battery lifespan of Mobile Nodes (MNs). This technique allows the proxy nodes, which connect the Adhoc-mode MNs to the nearest AP or BS, to share transit loads to balance their battery power consumption. The suggested algorithms outperform traditional optimization based on the SSF approach, which is solely based on RSS. [25] proposes deploying a System Selection and Mobility Management Agent (SSMMA) on both cars and networks to address handover concerns. Kang et al. [167] provided an optimized vertical handoff solution for the switching problem in a vehicle heterogeneous network interface.

-The strategy incorporates several metrics, including monetary cost, available bandwidth, and data transfer

Delay. Furthermore, it can accurately anticipate RSU distribution. The results show that the optimal stopping-based policy significantly outperforms several existing systems. Considering vehicle speed and network traffic factors, the number of handovers and latency can be reduced, while throughput can be increased [168]. To overcome the ubiquitous handover problem in heterogeneous networks, Bi et al.[169] proposed a performance-guaranteed optimized handover choice method. Vehicles can hand over a diverse environment using this technique, not only to achieve overall load balance among all access points but also to maximize data rate and vehicle fairness. Additionally, the data rates of handover vehicles are assessed during the decision-making process.

6.2. Approaches to vertical handover

Chiu et al. proposed a cross-layer quick handover technique dubbed the Vehicular Fast Handover Scheme (VFHS). To reduce the handover delay, the physical layer information is communicated with the MAC layer in this system. This system results in a speedy handover as well as a significant reduction in handover delay and packet loss. In [171]Ahmed et al. suggested an effective network-aided handover strategy that reduces vehicle scanning time during the handover procedure. The vehicle's RSU is determined by its velocity during the handover. However, the existing system requires a vehicle to scan until all of the nearby RSUs are found, which adds to the scanning time. The results show that the proposed technique effectively reduces the overall scanning delay and iterations that cars often endure. Proposed a new architecture that facilitates seamless mobile network mobility across heterogeneous networks. The overlapped reception of packets from several Access Routers (ARs) utilizing this technology greatly minimizes packet losses during handover while also lowering handover delay. Meneguette et al. [173] designed a Seamless Flow Mobility Management Architecture (SFMMA) to improve vehicular application quality of service. This design is built on vehicular network application classes and mobility management via the network.

The proposed SFMMA works with many network interfaces at once, aiming to reduce handover time, increase network throughput, and meet minimal latency and packet loss requirements for each type of vehicular network application. As a result of this work, the new architecture had a faster handover time, less packet loss, and less delay. Chung et al. [174] have suggested the WAVE Point Coordination Function (WPCF) protocol, a time-coordinated Medium Access Control (MAC) protocol for better V2I communications and handover. When compared to Point Coordination Function (PCF), Enhanced Distributed Channel Access (EDCA), or Hybrid Coordination Function (HCF) controlled channel access (HCCA) for V2I communications, the WPCF protocol can greatly improve utilization efficiency and accommodate more users. As a result, when compared to the performance of existing protocols, the suggested approach can drastically reduce handover delay. A contention-free WPCF changeover channel access method has also been presented to allow high-priority real-time data access.

A Time-Division Multiplexed (TDM) transmission system would waste time slots, whereas the WPCF technique does not. Overall, with the proposed WPCF scheme's preregistration process and efficient, reliable scheduling when opposed to employing EDCA for handover, the service disruption period is substantially less.

Table 4: Vertical handover works‘ comparison (NA: Not Available).

Author Name	**Handover Latency**	**Packet loss**	**Bandwidth**	**Delay**	**Throughput**	**Data rate**
Chiu et al. [170] (VFHS)	Decrease latency	Decreases packet loss	NA	Reduce delay	NA	NA
Gramaglia et Al. [175] (SILVIO)	NA	NA	A higher bandwidth	NA	NA	NA
Chung et al. [174] (WPCF)	NA	NA	NA	High priority real-time data	NA	NA
Dias et al. [176]	NA	No packet loss	NA	Very low delay	NA	NA

Shukla et al. [172]	Without reducing handover latency	Minimizes packet losses	NA	NA	NA	NA
Kumaran et Al. [168]	Minimize latency	NA	NA	NA	Maximize throughput	NA
Bi et al. [169]	NA	NA	NA	NA	NA	Maximize data rate
Dahiya et al. [177]	Reduce latency	Reduce packet loss	NA	NA	NA	NA
Ahmed et al. [171]	NA	NA	NA	Reduce delay	NA	NA
Meneguette et al. [173] (SFMMA)	Minimum latency	Low packet loss	NA	Low delay	Maximize throughput	NA
Joseph & Rajagopal [178]	NA	NA	NA	NA	NA	High data security

Dias et al. [176] suggested a mobility solution that combines MIPv6 and PMIPv6-based extended mobility protocols with a mobility manager that ensures seamless communication between vehicles and infrastructure. This technique can choose the most appropriate technology to keep the vehicle linked without interrupting any ongoing sessions. The suggested approach addresses both Layer 2 and Layer 3 handovers. For Layer 2 changeover, a mobility manager was created that scans available networks and initiates the turnover, while Layer 3 handover control mobility protocols were enhanced and tailored to work with the mobility manager. Experiments in real-world automobiles were carried out utilizing three different technologies: IEEE 802.11p, IEEE 802.11g, and 3G. Because traditional Wi-Fi standards introduce high handover latency and packet loss, it is vital to deploy IEEE 802.11-enabled RSUs in high-demand scenarios, the results indicate the benefits of a simpler communication standard for VANETs. The findings further show that if IEEE 802.11p is employed in both vehicles and RSUs, the suggested method can execute a smooth handover with very little delay and no packet loss.

Furthermore, [79] discussed FMIPv6 enhancement. This enhancement is based on a handover management strategy in a VANET scenario that employs the concept of tunnelling. Several criteria were considered, including handover latency, signalling overhead, performance comparison using tunnelling, packet loss, service disruption duration, and network longevity. Handover delay, packet loss, signalling overhead, the number of packets required for handover, and service disruption time are all reduced. As a result, these strategies must be evaluated in a more realistic setting and applied to a real-world wireless environment.

Gramaglia et al. [175] have suggested Seamless Internet 3G and Opportunistic WLAN Vehicular Internet Connectivity (SILVIO). It's an internet connectivity solution for multi-hop automobile ad-hoc networks. Users can benefit from increased bandwidth while operators can relieve their overburdened cellular networks by adopting SILVIO. SILVIO delivers seamless communication without the need for signalling. Furthermore, the findings of real traffic traces from Madrid City reveal that by employing SILVIO, the cellular network can be offloaded by up to 80%.

In addition, [179] presented a novel hybrid interworking method that allows access to mobile internet and standard IP services via a mobility management mechanism. Furthermore, the system focuses on urban vehicle scenarios and allows for seamless communications regardless of network operator roaming agreements. Despite varied mobility patterns and the heterogeneity of the supporting radio access technologies, this new hybrid method provides for flawless IP session transfer. The provided approach outperforms competing protocols such as the optimized version of MIPv6, NEMO BS, conventional HIP, and Novaczki's micro-mobility scheme for HIP, according to the performance analysis. In contrast, in

[180] an extendable simulation environment was created by merging the simulation tool NS2 with the VANET-Mobisim user mobility model. In NS2, a VHO mechanism based on Media Independent Handover (MIH) and a multi-mode node model are established. Element. The communication capabilities of multi-mode VUs in a heterogeneously integrated UMTS and WLAN network are assessed. The throughput of VUs is only a little affected by their velocity. However, frequent handoffs caused by users' high speeds may compromise user QoS in terms of packet loss and handoff latency.

Furthermore, while other users' modest traffic load may not have a significant impact on user performance, excessive traffic load will reduce user performance, particularly in WLAN. As a result, the upward handoff delay is significantly higher than the downward handoff latency. Ghosh et al. [181] on the other hand, introduced a new VANET testbed that is now being deployed at Middlesex University in London. This research presents a new proactive handover performance model, which is then compared to previous methodologies. A probabilistic approach based on accurate propagation models from a genuine testbed is necessary to reliably derive relevant values of TBVH and NDT. Furthermore, this work demonstrates how accurate TBVH and NDT values may be employed for proactive channel allocation. Furthering handover research, Joseph & Rajagopal introduced a new system [178] that allows effective handoff between WLAN and WiMAX while also providing a big coverage and multimedia application to the vehicle. Location preservation and vehicle security are achieved using Elliptic Curve Diffie-Hellman (ECDH) cryptography with a public key.

Conclusion

The integration of VANET heterogeneous wireless networks in the literature was reviewed and compared in this paper. The success of vehicle communication relies heavily on the integration of VANET heterogeneous wireless networks. On the other hand, this work will aid future researchers in gaining insight into the collaboration of vehicle heterogeneous networks in constructing VANETs and improving driver safety. As a result, it is recommended that researchers test their findings not just in small-scale homogeneous networks but also in large-scale heterogeneous networks.

I. REFERENCES

[1] L. J. Chen, T. Sun, G. Yang and M. Gerla, "USHA: a simple and practical seamless vertical handoff solution," in *IEEE Consumer Communications and Networking Conference*, 2006.

[2] "IEEE Standard for Local and Metropolitan Area Networks Networks – part 21: Media Independent Handover, Technical report," IEEE, 2009.

[3] A. De-La-Oliva, T. Melia, A. Vidal, C. Bernardos, I. Soto and A. Banchs, "IEEE 802.21 enabled mobile terminals for optimized WLAN/3G handovers: a case study, ACM Mobile Computing and Communications Review," vol. 11, no. 2, pp. 29-40, 2007.

[4] T. Buburuzan and L. Nyamen, "Performance evaluation of an enhanced IEEE 802.21 handover model," in *1st Workshop on Wireless Broadband Access for Communities and Rural Developing Regions*, Karlstad, 2008.

[5] A. Dutta, S. Das, D. Famolari, Y. Ohba, K. Taniuchi, V. Fajardo, R. Lopez, T. Kodama and H. Schulzrinne, "Seamless proactive handover across heterogeneous access networks," *Springer Wireless Personal Communications,* vol. 43, no. 3, pp. 837-855, 2007.

[6] W. H. Organization, "WHO global status report on road safety (9 May 2016): reviews fact sheet on Road Traffic Injuries," World Health Organization, 2016.

[7] W. H. Organization, "WHO Fact Sheet on Road Traffic Injuries(November 2016): ―Road traffic injuries," World Health Organization, 2016.

[8] J. Roth, "Harmonizing Cars and Humans in Japan‘s Era of Mass Automobility," *The Asia Pacific Journal,* vol. IX, no. 3, 2011.

[9] [Online]. Available: Website: http://www.itsa.org/.

[10] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in *IEEE Vehicular Technology Conference*, 2008.

[11] N. Choi, S. Choi, Y. Seokt, T. Kwon and Y. Choi, "A Solicitation-based IEEE 802.11p MAC Protocol for Roadside to Vehicular Networks," *Mobile Networking for Vehicular Environments,* pp. 91-96, May 2007.

[12] IEEE Standard for Information technology, "Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements –," ―*Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments,* pp. 1-51, 15 July 2010.

[13] G. Araniti, C. Campolo, M. Condoluci, A. Iera and A. Molinaro, "LTE for vehicular networking: a survey," *IEEE Communications Magazine,* vol. 51, no. 5, pp. 148-157, May 2013.

[14] A. Benslimane, T. Taleb and R. Sivaraj, "Dynamic Clustering-Based Adaptive Mobile Gateway Management in Integrated VANET - 3G Heterogeneous Wireless Networks," *IEEE Journal on Selected Areas in Communications,* vol. 29, no. 3, pp. 559-570, March 2011.

[15] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato and Y. Nemoto, "A Stable Routing Protocol to support ITS services in VANET Networks," *IEEE Transactions on vehicular technology,* vol. 56, no. 6, pp. 3337-3347, November 2007.

[16] M. Heddebaut, J. Rioult, J. P. Ghys, C. Gransart and S. Ambellouis, "Broadband vehicle-to-vehicle communication using an extended autonomous cruise control sensor," *Meas. Sci. Technol.,* vol. 16, no. 6, pp. 1363-1373, June 2005.

[17] R. D. M. Shulman, "Third annual report of the crash avoidance metrics partnership April 2003-March 2004," *Nat. Highway Traffic Safety Admin. (NHTSA),* February 2005.

[18] C. Bergese, A. Braun and E. Porta, "Inside CHAUFFEUR," in *Proc. 6th ITS World Congr*, Toronto, ON, Canada, 1999.

[19] L. Andreone and C. Ricerche, "Activities and applications of the vehicle to vehicle and vehicle to infrastructure communication to enhance road safety," in *Proc. 5th Eur. Congr. Exhib. ITS*, Hannover, Germany, 2005.

[20] R. Kruger, H. Fubler, M. Torrent-Moreno, M. Transier, H. Hartenstein and W. Effelsberg, "Statistical analysis of the FleetNet highway movement patterns," University of Mannheim, Mannheim, Germany, 2005.

[21] W.-B. Zhang, H. Tan, A. Steinfield, B. Bougler, D. Empey, K. Zhou and M. Tomizuka, "Implementing advanced vehicle control and safety systems (AVCSS) for highway maintenance operations," in *Proc. 6th Annu. World Congr. ITS*, Toronto, ON, Canada, 1999.

[22] F. Liu and L. Shan, "Heterogeneous vehicular communication architecture and key technologies," *ZTE Communication,* vol. 8, no. 4, pp. 39-44, August 2010.

[23] A. Vinel, "3GPP LTE versus IEEE 802.11p/WAVE: Which technology can support cooperative vehicular safety applications," *IEEE Wireless Communication Letters,* vol. 1, no. 2, pp. 125-128, February 2012.

[24] E. Ndashimye, S. K. Ray, N. I. Sarkar and J. A. Gutiérrez, "Vehicle-toinfrastructure communication over multi-tier heterogeneous networks: A survey," *Computer Networks,* vol. 112, pp. 144-166, 2017.

[25] E. Hossain, G. Chow, V. C. C. Leung, R. D. McLeod, J. Mišic´, V. W. Wong and O. Yang, "Vehicular telematics over heterogeneous wireless networks: A survey," *Computer Communications,* vol. 33, pp. 775-793, 2010.

[26] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin and T. Weil, "Vehicular networking: a survey and tutorial on requirements,architectures, challenges, standards and solutions," *IEEE Communications Surveys & Tutorials,* vol. 13, no. 4, pp. 584-616, 2011.

[27] X. Wu, S. Subramanian, W. R. G. Guha, J. Li, K. W. Lu, A. Bucceri and T. Zhang, "Vehicular communications using DSRC: Challenges, enhancements, and evolution," *IEEE Journal on Selected Areas in Communications,* vol. 31, no. 9, pp. 399-408, 2013.

[28] S. Al-Sultan, M. Al-Doori, A. Al-Bayatti and H. Zedan, "A comprehensive survey on vehicular Ad Hoc network," *Elsevier Journal of Network and Computer Applications,* vol. 37, pp. 380-392, January 2014.

[29] N. Lu, N. Cheng, N. Zhang, X. Shen and J. Mark, "Connected vehicles:Solutions and challenges," *IEEE Internet Things Journal,* vol. 1, no. 4, pp. 289-299, August 2014.

[30] F. Dressler, H. Hartenstein, O. Altintas and O. Tonguz, "Inter-vehicle communication: Quo vadis," *IEEE Communication Magazine,* vol. 52, no. 6, pp. 170-177, June 2014.

[31] W. Viriyasitavat, M. Boban, H.-M. Tsai and A. Vasilakos, "Vehicular communications: survey and challenges of channel and propagation models," *IEEE Vehicular Technology Magazine,* vol. 10, no. 2, pp. 55-66, June 2015.

[32] M. Sahasrabudhe and M. Chawla, "Survey of Applications based on Vehicular Ad-Hoc Network (VANET) Framework," *International Journal of Computer Science and Information Technologies (IJCSIT),* vol. 5, no. 3, pp. 3937-3942, 2014.

[33] S. Kato, M. Hiltunen, K. Joshi and R. Schlichting, "Enabling vehicular safety applications over LTE networks," *International Conference on Connected Vehicles and Expo (ICCVE),* pp. 747-752, 2-6 December 2013.

[34] H. V. Nejad, A. Ramazani, T. Mohammadi and W. Mansoor, "A survey on context-aware vehicular network applications," *Vehicular Communications,* vol. 3, pp. 43-57, 2016.

[35] F. Liu and L. Shan, "Heterogeneous vehicular communication architecture and key technologies," *ZTE Communication,* vol. 8, no. 4, pp. 39-44, 2010.

[36] U. L. Mane and A. A. Junnarkar, "A Survey on Techniques and Fundamentals of Internet Access in VANET-INTERNET Integration Scenarios," *International Journal of Computer Science and Information Technologies (IJCSIT),* vol. 6, no. 3, pp. 2035-2039, 2015.

[37] M. S. Anwer and C. Guy, "A Survey of VANET Technologies," *Journal of Emerging Trends in Computing and Information Sciences,* vol. 5, no. 9, pp. 661-671, 2014.

[38] T. Mangel, T. Kosch and H. Hartenstein, "A comparison of UMTS and LTE for vehicular safety communication at intersections," *IEEE ehicular Networking Conference (VNC),* p. 293–300, 2010.

[39] Z. Mir, J. Toutouh, F. Filali and E. Alba, "QoS-Aware radio access technology (RAT) selection in hybrid vehicular networks," *Springer Communication Technologies for Vehicles,* pp. 117-128, 2015.

[40] Z. Mir and F. Filali, "?LTE and IEEE 802.11 p for vehicular networking:a performance evaluation," *EURASIP Journal on Wireless Communications and Networking,* pp. 1-15, 2014.

[41] M. Kihl, K. Bür, P. Mahanta and E. Coelingh, "3GPP LTE downlink scheduling strategies in vehicle-to-infrastructure communications for traffic safety applications," *IEEE Symposium on Computers and Communications (ISCC),* pp. 448-453, July 2012.

[42] G. Remy, S.-M. Senouci, F. Jan and Y. Gourhant, "LTE4V2X—Impact of high mobility in highway scenarios," *Global Information Infrastructure Symposium (GIIS),* pp. 1-7, August 2011.

[43] L.-C. Tung and M. Gerla, "LTE resource scheduling for vehicular safety applications," *The 10th Annual Conference on Wireless On-demand Network Systems and Services (WONS),* pp. 116-118, March 2013.

[44] K. Zheng, Q. . Zheng, P. Chatzimisios, W. Xiang and Y. Zhou, "Heterogeneous Vehicular Networking: A Survey on Architecture, Challenges, and Solutions,," *IEEE Communications Surveys & Tutorials,* vol. 17, pp. 2377-2396, 2015.

[45] N. S. Mahendri, "A Survey on Vehicular Ad-hoc Networks (VANETs)," *International Journal of Advanced Research in Computer Engineering &Technology (IJARCET),* vol. 4, no. 5, May 2015.

[46] "IEEE Trial-use Standard for Wireless Access in Vehicular Environments (WAVE),Resource Manager," 2006. [Online]. Available: http://dx.doi.org/10. 1109/IEEESTD.2006.246485..

[47] C. Communication Consortium, "Car2car communication consortium manifesto," [Online]. Available: Http://car-to-car.org/index.php?id=31.

[48] "United States Department of Transportation, Office of the Assistant Secretary for Research and Technology: Vehicle-to-Infrastructure (V2I) communications for safety," [Online]. Available: http://www.its.dot.gov/factsheets/v2isafety_factsheet.htm.

[49] S. Olariu and M. C. Weigle, "Vehicular networks: from theory to practice," *Chapman and Hall/CRC,* 17 March 2009.

[50] A. Festag et al., "Now-network on wheels: project objectives,technology and achievements," *Proceedings of the 5th international workshop on intelligent transportation (WIT),* pp. 211-216, March 2008.

[51] M. L. Sichitiu and M. Kihl, "Inter-vehicle communication systems: a survey," *IEEE Communications Surveys & Tutorials,* vol. 10, no. 2, pp. 88-105, August 2008.

[52] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments," *Mercedes-Benz Research & Development North America, Inc.,* 2008.

[53] "FCC allocates spectrum in 5.9 GHz range for intelligent transportation systems uses: Action will improve the efficiency of the nation‘s transportation infrastructure," pp. ET 99-5, 21 October 1999.

[54] Y. Toor, P. Muhlethaler and A. Laouiti, "Vehicle ad hoc networks:applications and related technical issues," *IEEE Communications Surveys & Tutorials,* vol. 10, no. 3, pp. 74-88, 2008.

[55] A. Islam and N. H. M. . Bhuyan, "The Effect of Radio Channel Modelling on the Network Performance in VANET," 2015.

[56] E. T. S. Institute, "Intelligent transport systems (ITS); radio communications equipment operating in the 5 855 MHz to 5 925 MHz frequency band," Technical Report ETSI EN 302 571 V1.2.0, ETSI, France, 2013.

[57] A. Sharma, B. Raj, K. Kapoor and D. Jyoti, "a Novel Approach for Detection of Traffic Congestion in NS2," *International Journal of Advance Research, Ideas and Innovations in Technology (IJARIIT),* vol. 2, no. 4, 2016.

[58] F. D. Cunha, A. Boukerche, L. Villas, A. C. Viana and A. F. Loureiro, "Data Communication in VANETs Applications," *Research Report RR-8498,* March 2014.

[59] J. J. Blum, A. Eskandarian and L. J. Hoffman, "Challenges of inter-vehicle ad hoc networks," *IEEE Transactions on Intelligent Transportation Systems,* vol. 5, no. 4, pp. 47-51, 2004.

[60] S. Yousefi, M. S. Mousavi and M. Fathy, "Vehicular ad hoc networks (vanets): challenges and perspectives," *Proceedings of the 6th international conference on ITS telecommunications,* pp. 761-766, July 2006.

[61] J. Jakubiak and Y. Koucheryavy, "State of the art and research challenges for VANETs," *IEEE Consumer communications and networking conference CCNC,* pp. 912-916, 2008.

[62] M. Nekovee, "Sensor networks on the road: the promises and challenges of vehicular ad hoc networks and grids," in *Workshop on ubiquitous computing and e-Research*, 2005.

[63] C. Han, M. Dianati, R. Tafazolli, R. Kernchen and X. Shen, "Analytical study of the IEEE 802.11p MAC sublayer in vehicular networks," *IEEE Transactions on Intelligent Transportation Systems ,* vol. 13, no. 2, pp. 873-886, 2012.

[64] P. Papadimitratos, A. La Fortelle, K. Evenssen, R. Brignolo and S. Cosenza, "Vehicular communication systems: Enabling technologies applications, and

future outlook on intelligent transportation," *IEEE Communications Magazine,* vol. 47, no. 11, pp. 84-95, November 2009.

[65] L. Lei, Y. Zhang, X. Shen, C. Lin and Z. Zhong, "Performance Analysis of Device-to Device Communications with Dynamic Interference Using Stochastic Petri Nets," *IEEE Transactions on Wireless Communications,* vol. 12, no. 12, pp. 6121-6141, 2013.

[66] L. Lei, Z. Zhong, C. Lin and X. Shen, "Operator controlled device-todevice communications in LTE-advanced networks," *IEEE Wireless Communications,* vol. 19, no. 3, pp. 96-104, June 2012.

[67] 3. G. P. Project, "Technical Specification Group Radio Access Network," *Study on LTE Device to Device Proximity Services - Radio Aspects (Release 12) 3GPP TR 36.843,* vol. 12.0.1, March 2014.

[68] IEEE, " IEEE Standard for Information Technology-Local and Metropolitan Area Networks-Specific Requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6:," *Wireless Access in Vehicular IEEE Environments, Std.802.11p-2010,* pp. 1-51, July 2010.

[69] G. Korkmaz, E. Ekici, F. Özgüner and Ü. Özgüner, "Urban multi-hop broadcast protocol for inter-vehicle communication systems," in *Proceeding of 1st ACM International Workshop on Vehicle Ad Hoc Networks*, 2004.

[70] G. Korkmaz, E. Ekici and F. Ozguner, "Black-burst-based multi-hop broadcast protocols for vehicular networks," *IEEE Transactions on Vehicular Technology,* vol. 56, no. 5, pp. 3159-3167, 2007.

[71] Q. Yang and L. Shen, "A multi-hop broadcast scheme for propagation of emergency messages in VANET," in *Proc. 12th IEEE ICCT*, Nanjing,China, 2010.

[72] M. Slavik and I. Mahgoub, "Spatial distribution and channel quality adaptive protocol for multihop wireless broadcast routing in VANET," *IEEE Transactions on Mobile Computing,* vol. 12, no. 4, pp. 722-734, Februry 2013.

[73] M. Barradi, A. Hafid and S. Aljahdali, "Highway multihop broadcast protocols for vehicular networks," in *Proceeding IEEE ICC*, Ottawa,Canada, 2012.

[74] M. Slavik and I. Mahgoub, "Stochastic broadcast for VANET," in *Proceeding 7th IEEE CCNC*, Las Vegas, NV, USA,, 2010.

[75] M. Pan, P. Li and Y. Fang, "Cooperative communication aware link scheduling for cognitive vehicular networks," *IEEE Journal on Selected Areas in Communications,* vol. 30, no. 4, pp. 760-768, May 2012.

[76] G. Remy, S.-M. Senouci, F. Jan and Y. Gourhant, "LTE4V2X: LTE for a centralized VANET organization," *IEEE Global Telecommunications Conference (GLOBECOM 2011),* pp. 1-6, 5-9 December 2011.

[77] M. Kihl, K. Bür, P. Mahanta and E. Coelingh, "3GPP LTE downlink scheduling strategies in vehicle-to-infrastructure communications for traffic safety applications," *IEEE Symposium on Computers and Communications (ISCC),* pp. 448-453, July 2012.

[78] G. Remy, S.-M. Senouci, F. Jan and Y. Gourhant, "LTE4V2X—Impact of high mobility in highway scenarios," *Global Information Infrastructure Symposium (GIIS),* pp. 1-7, August 2011.

[79] M. Gerla and L. Kleinrock, "Vehicular networks and the future of the mobile internet," *Computer Networks,* vol. 55, no. 2, pp. 457-469, February 2011.

[80] M. S. Anwer and C. Guy, "A Survey of VANET Technologies," *Journal of Emerging Trends in Computing and Information Sciences,* vol. 5, no. 9, pp. 661-671, September 2014.

[81] T. Mangel, T. Kosch and H. Hartenstein, "A comparison of UMTS and LTE for vehicular safety communication at intersections," *IEEE Vehicular Networking Conference (VNC),* p. 293–300, December 2010.

[82] G. Giambene and M. Marandola, "Internet access in hybrid terrestrial and satellite mobile communication systems," *IEEE Vehicular Technology Conference (VTC),* pp. 2811-2815, 2004.

[83] B. Aslam, P. Wang and C. Zou, "Pervasive Internet access by vehicles through satellite receive-only terminals," *Proceedings of 18th International Conference on Computer Communications and Networks,* pp. 1-6, 3-6 August 2009.

[84] Q. Li, Y. Wu, S. Feng, P. Zhang and Y. Zhou, "Cooperative uplink link adaptation in 3GPP LTE heterogeneous networks," *IEEE 77th Vehicular Technology Conference (VTC),* pp. 1-5, 2013.

[85] L.-J. Chen, G. Yang, T. Sun, M. Sanadidi and M. Gerla, "Enhancing QoS support for vertical handoffs using implicit/explicit handoff notifications," in *2nd IEEE International Conference on Quality of Service in Heterogeneous Wired/ Wireless Networks*, 2005.

[86] Y. Chen, J. Hsia and Y. Liao, "Advanced seamless vertical handoff architecture for WiMAX and WiFi heterogeneous networks with qos guarantees," *Elsevier Computer Communications,* vol. 32, no. 2, p. 281–293, 2009.

[87] R. Corvaja, "QoS analysis in overlay Bluetooth–WiFi networks with profile based vertical handover," *IEEE Transactions on Mobile Computing ,* vol. 5 , no. 12, p. 1679–1690. , 2006.

[88] M. Kassar, B. Kervella and G. Pujolle, "Autonomic-oriented architecture for an intelligent handover management scheme," in *6th IEEE Annual Communication Networks and Services Research Conference*, 2008.

[89] M. Kassar, B. Kervella and G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Elsevier Computer Communications,* vol. 31, no. 10, 2008.

[90] E. Stevens-Navarro, Y. Lin and V. Wong, "An MDP-based vertical handoff decision algorithm for heterogeneous wireless networks," *IEEE Transactions on Vehicular Technology,* vol. 57, no. 2, p. 1243–1254, 2008.

[91] M. Kassar, B. Kervella and G. Pujolle, "Architecture of an intelligent inter-system handover management scheme," in *IEEE Future Generation Communication and Networking Conference,*, 2007.

[92] A. Singhrova and N. Prakash, "A review of vertical handoff decision algorithm in heterogeneous networks," in *4th ACM International Conference on Mobile Technology, Applications, and Systems*, New York, NY, USA, 2007.

[93] L. Chen, T. Sun, B. Chen, V. Rajendran and M. Gerla, "A smart decision model for vertical handoff," in *4th International Workshop on Wireless Internet and Reconfigurability*, Athens, Greece, 2004.

[94] V. Gupta, "IEEE 802.21 media independent handover tutorial," *IEEE 802.21 Working Group Meeting,* July 2006.

[95] T. Inzerilli, A. Vegni, A. Neri and R. Cusani, "A location-based vertical handover algorithm for limitation of the ping-pong effect," in *IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, 2008.

[96] F. Siddiqui and S. Zeadally, "Mobility management across hybrid wireless networks: trends and challenges," *Computer Communications,* vol. 29, no. 9, p. 1363–1385, 2006.

[97] A. Dutta, S. Das, D. Famolari, Y. Ohba, K. Taniuchi, V. Fajardo, R. Lopez, T. Kodama and H. Schulzrinne, "Seamless proactive handover across heterogeneous access networks," *Springer Wireless Personal Communications,* vol. 43, no. 3, p. 837–855, 2007.

[98] P. Goyal and S. Saxena, "A dynamic decision model for vertical handoffs across heterogeneous wireless networks," in *World Academy of Science, Engineering and Technology*, 2008.

[99] P. Nay and C. Zhou, "Vertical handoff decision algorithm for integrated UMTS and LEO satellite networks," in *IEEE International Conference on Communications and Mobile Computing*, 2009.

[100] I. Lassoued, J. Bonnin, B. Hamouda and A. Belghith, "A methodology for evaluating vertical handoff decision mechanisms," in *7th IEEE International Conference on Networking*, 2008.

[101] E. Stevens-Navarro and V. Wong, "Comparison between vertical handoff decision algorithms for heterogeneous wireless networks," in *63rd IEEE Vehicular Technology Conference*, 2006.

[102] J. Jo and J. Cho, "A cross-layer vertical handover between mobile WiMAX and 3G networks," in *IEEE Wireless Communications and Mobile Computing Conference*, 2008.

[103] W. Ying, Y. Jun, Z. Yun, L. Gen and Z. Ping, "Vertical handover decision in an enhanced media independent handover framework," in *IEEE Wireless Communications and Networking Conference*, 2008.

[104] B. S. Horrich and P. Godlewski, "Neural networks for adaptive vertical handover decision," in *5th IEEE International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks*, 2007.

[105] M. Fouladian, F. Hendessi, A. Shafieinejad, M. Rahimi and M. Bayat, "A new method for vertical handoff between WLANs and UMTS in boundary conditions," in *IEEE International Conference on Computer Engineering and Technology*, 2009.

[106] K. Fall and K. Varadhan, "Ns Notes and Documents," *The VINT Project. UC Berkeley,LBL, USC/ISI, and Xerox PARC,* June 2009.

[107] D. Wright, "Maintaining QoS during handover among multiple wireless access technologies," in *IEEE/ACM International Conference on the Management of Mobile Business*, Washington, DC, USA,, 2007.

[108] OPNET Technologies, "OPNET Modeler," [Online]. Available: <http://www.opnet.com/solutions/network_rd/modeler.html>..

[109] MathWorks, "Mathlab and Simulink for Technical Computing," [Online]. Available: <http://www.mathworks.com/>..

[110] Advanced Network Technology Division, "National Institute of Standards and Technology," [Online]. Available: http://www.antd.nist.gov/seamlessandsecure/.

[111] N. Baldo, F. Maguolo, M. Miozzo, M. Rossi and M. Zorzi, "ns2-MIRACLE: a modular framework for multi-technology and cross-layer support in network simulator 2," in *Proceedings of the 2nd International Conference on Performance Evaluation Methodologies and Tools ICST*, Brussels, Belgium, 2007.

[112] M. Bernaschi, F. Cacace and G. Iannello, "Vertical handoff performance in heterogeneous networks," in *IEEE International Conference on Parallel Processing*, 2004.

[113] D.-H. Kim, W.-T. Kim, H.-G. Lee, S.-J. Kim and C.-H. Lee, "A performance evaluation of vertical handover architecture with low latency handover," in *IEEE nternational Conference on Convergence and Hybrid Information Technology*, 2008.

[114] P. Pawar, K. Wac, B. van Beijnum, P. Maret, A. van Halteren and H. Hermens, "Context-aware middleware architecture for vertical handover support to multi-homed nomadic mobile services," in

ACM Symposium on Applied Computing, Fortaleza, Ceara, Brazil, 2008.

[115] J. Sen and A. Ukil, "A QoS-aware end-to-end connectivity management algorithm for mobile applications," in *Proceedings of the Third Annual ACM Bangalore Conference*, New York, NY, USA, 2010.

[116] I.-S. Jang, W.-T. Kim, J.-M. Park and Y.-J. Park, "Mobile multicast mechanism based MIH for efficient network resource usage in heterogeneous networks," in *12th International IEEE Conference on Advanced Communication Technology*, 2010.

[117] T. Buburuzan and L. Nyamen, "Performance evaluation of an enhanced IEEE 802.21 handover model," in *1st Workshop on Wireless Broadband Access for Communities and Rural Developing Regions*, Karlstad, 2008.

[118] L. Chen, T. Sun, G. Yang and M. Gerla, "USHA: a simple and practical seamless vertical handoff solution," in *IEEE Consumer Communications and Networking Conference*, 2006.

[119] A. Sur and D. Sicker, "Multi layer rules based framework for vertical handoff," in *2nd IEEE International Conference on Broadband Networks*, 2005.

[120] H. Kwon, M.-J. Yang, A.-S. Park and S. Venkatesan, "Handover prediction strategy for 3G–WLAN overlay networks," in *IEEE Network Operations and Management Symposium*, 2008.

[121] M. Li, S. Chen and D. Xie, "A multi-step vertical handoff mechanism for cellular multi-hop networks," in *2nd ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks*, New York,NY, USA,, 2007.

[122] B.-J. Chang and J.-F. Chen, "Cross-layer-based adaptive vertical handoff with predictive RSS in heterogeneous wireless networks," *IEEE Transactions on Vehicular Technology,* vol. 57, no. 6, p. 3679–3692, 2008.

[123] A. Mehbodniya and J. Chitizadeh, "An intelligent vertical handoff algorithm for next generation wireless networks," in *2nd IFIP/IEEE International Conference on Wireless and Optical Communications Networks*, 2005.

[124] L. Xia, J. Ling-Ge, H. Chen and L. Hong-Wei, "An intelligent vertical handoff algorithm in heterogeneous wireless networks," in *IEEE International Conference on Neural Networks and Signal Processing*, 2008.

[125] I. Joe and S. Hong, "A mobility-based prediction algorithm for vertical handover in hybrid wireless networks," in *2nd IEEE/IFIP International Workshop on*, 2007.

[126] M. Ylianttila, J. Makela and K. Pahlavan, "Analysis of handoff in a location-aware vertical multi-access network," *Elsevier Computer Networks,* vol. 47, no. 2, 2005.

[127] M. Mani and N. Crespi, "WLC14-5: handover criteria considerations in future convergent networks," in *IEEE Global Telecommunications Conference*, 2006.

[128] F. Phiri and M. Murthy, "WLAN–GPRS tight coupling based interworking architecture with vertical handoff support," *Springer Wireless Personal Communications,* vol. 40, no. 2, p. 137–144, 2007.

[129] S. Lee, K. Sriram, K. Kim, Y. Kim and N. Golmie, "Vertical handoff decision algorithms for providing optimized performance in heterogeneous wireless networks," *IEEE Transactions on Vehicular Technology,* vol. 58, no. 2, p. 865–881, 2009.

[130] D. Kim, S. Koh and V. Leung, "On the packet reordering of mSCTP for vertical handover in heterogeneous wireless networks," in *IEEE 68th Vehicular Technology Conference*, 2008.

[131] H. Attaullah, F. Iqbal and M. Javed, "Intelligent vertical handover decision model to improve QoS," in *IEEE Third International Conference on Digital Information Management*, 2008.

[132] I. Joe and M. Shin, "A mobility-based prediction algorithm with dynamic lgd triggering for vertical handover," in *7th IEEE Consumer Communications and Networking Conference*, 2010.

[133] T. Kim, S.-w. Han and Y. Han, "A QoS-aware vertical handoff algorithm based on service history information," *IEEE Communications Letters ,* vol. 14, no. 6, p. 527–529, 2010.

[134] J. Sen and A. Ukil, "A QoS-aware end-to-end connectivity management algorithm for mobile applications," in *Proceedings of the Third Annual ACM Bangalore Conference*, New York, NY, USA,, 2010.

[135] B. Jung, M. Choi, H. Youn and O. Song, "Vertical handover based on the prediction of mobility of mobile node," in *8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)*, 2010.

[136] A. Bazzi, G. Pasolini and C. Gambetti, "Shine: simulation platform for heterogeneous interworking networks," in *IEEE International Conference on Communications*, 2006.

[137] K. Tsukamoto, T. Yamaguchi, S. Kashihara and Y. Oie, "Implementation design of handover management scheme for efficient multimodal communication," in *IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, 2008.

[138] K. Yang, I. Gondal, B. Qiu and L. Dooley, "Combined SINR based vertical handoff algorithm for next generation heterogeneous wireless networks," in *IEEE Global Telecommunications Conference*, 2007.

[139] A. Hasswa, N. Nasser and H. Hossanein, "Generic vertical handoff decision function for heterogeneous wireless," in *2nd IFIP/IEEE International*

Conference on Wireless and Optical Communications Networks, 2005.

[140] J. Jo and J. Cho, "A cross-layer vertical handover between mobile WiMAX and 3G networks," in *IEEE Wireless Communications and Mobile Computing Conference*, 2008.

[141] G. Mapp, F. Shaikh, D. Cottingham, J. Crowcroft and J. Baliosian, "Y-Comm: a global architecture for heterogeneous networking," in *3rd ICST/ACM International Conference on Wireless Internet*, Belgium, 2007.

[142] Open Handset Alliance, "Android".

[143] D. Niyato and E. Hossain, "Dynamics of network selection in heterogeneous wireless networks: an evolutionary game approach," *IEEE Transactions on Vehicular Technology ,* vol. 58, no. 4, p. 2008–2017, 2009.

[144] J. Latvakoski, P. Valitalo and T. Vaisanen, "Vertical handover during a VoIP call in hybrid mobile ad hoc networks," in *IEEE Wireless Telecommunications Symposium*, 2008.

[145] I.-C. Lin, C.-S. Shieh and W. Lai, "Avoidance of redundant retransmission in vertical handover by modified stream control transmission protocol," in *3rd IEEE International Conference on Innovative Computing Information and Control*, 2008.

[146] H. Liao, L. Tie and Z. Du, "A vertical handover decision algorithm based on fuzzy control theory," in *IEEE International Multi-Symposiums on Computer and Computational Sciences*, Los Alamitos, CA, USA,, 2006.

[147] A. N. T. Division, "Seamless and Secure Mobility," National Institute of Standards and Technology, [Online]. Available: http://www.antd.nist.gov/seamlessandsecure/.

[148] S. Lee, K. Sriram, K. Kim, Y. H. Kim and N. Golmie, "Vertical Handoff Decision Algorithms for Providing Optimized Performance in Heterogeneous Wireless Networks," *IEEE transaction on vehicular technology,* vol. 58, no. 2, February 2009.

[149] W. Liao and Y. Chen, "Supporting vertical handover between universal mobile telecommunications system and wireless LAN for real-time services," *IEEE Institution of Engineering and Technology Communications ,* vol. 2, no. 1, p. 75–81, 2008.

[150] H. Liao, Tie and Z. Du, "A vertical handover decision algorithm based on fuzzy control theory," in *IEEE International Multi-Symposiums on Computer and Computational Sciences*, Los Alamitos, CA, USA,, 2006.

[151] C. Liu and C. Zhou, "An improved interworking architecture for UMTS–WLAN tight coupling," in *IEEE Wireless Communications and Networking Conference*, 2005.

[152] M. Mani and N. Crespi, "WLC14-5: handover criteria considerations in future convergent networks," in *IEEE Global Telecommunications Conference*, 2006.

[153] S. Asadullah, A. Mahmoud and A. Amara, "Vertical handoff characterization for sip and mSCTP based UMTS–WLAN integration solutions," in *IEEE–GCC 2007*, 2007.

[154] E. Paik, S. Heo, H. Kim, J. Jin, S.-C. Lee and S. Lee, "Seamless vertical handover using multi-homed mobile access point," in *IEEE Global Telecommunications Conference*, 2008.

[155] S.-H. Kwon, S.-J. Koh, T.-W. Um and W. Ryu, "Mobile SCTP with bicasting for vertical handover," in *3rd IEEE International Conference on Convergence and Hybrid Information Technology*, 2008.

[156] A. Taha, H. Hassanein and H. Mouftah, "Exploiting vertical handoffs in next generation radio resource management," in *Proceedings of the International Conference on Communications*, 2006.

[157] D. Kwon and A. Park, "Methods for seamless vertical handoff between UMTS and WLAN," in *9th IEEE International Conference on Advanced Communication Technology*, 2007.

[158] J. M-Barja, C. Calafate, J.-C. Cano and P. Manzoni, "An overview of vertical handover techniques: algorithms, protocols and tools,," *Computer Communications,* vol. 34, no. 8, pp. 985-997, June 2011.

[159] K. Zhu, D. Niyato, P. Wang, E. Hossain and D. In Kim, "Mobility and handoff management in vehicular networks: a survey," *Wireless Communications and Mobile Computing,* vol. 11, no. 4, pp. 459-476, 2011.

[160] Y. Chen, C. Hsu and C. Cheng, "Network mobility protocol for vehicular ad hoc networks," *International Journal of Communication Systems,* vol. 27, no. 11, pp. 3042-3063, November 2014.

[161] A. Magnano, X. Fei and A. Boukerche, "Predictive mobile IP handover for vehicular networks," *40th IEEE Conference on Local Computer Networks (LCN), Clearwater Beach,* pp. 338-346, 26-29 Octorber 2015.

[162] S. K. Ray, H. Sirisena and D. Deka, "LTE-advanced handover: an orientation matching-based fast and reliable approach," *38th Annual IEEE Conference on Local Computer Networks,* pp. 280-283, 21-24 Octorber 2013.

[163] S. Ray, K. Pawlikowski and H. Sirisena, "Handover in mobile WiMAX networks: the state of art and research issues," *IEEE Communications Surveys & Tutorials,* vol. 12, no. 3, pp. 376-399, 2010.

[164] Y. T. Chang, J. W. Ding, C. H. Ke and I. Y. Chen, "A Survey of Handoff Schemes for Vehicular Ad-Hoc Networks," *IWCMC '10 Proceedings of the 6th International Wireless Communications and Mobile Computing Conference,* pp. 1228-1231, June–July 2010.

[165] U. Kumaran, "Vertical Handover in Vehicular Ad-hoc Networks - A Survey," *International Journal of Latest Trends in Engineering and Technology (IJLTET),* vol. 3, no. 4, pp. 132-138, March 2014.

[166] S. Midya, K. Majumder, A. Roy and D. De, "Vertical Handoff Mechanisms in VANET: A Survey," *M ICTCS '16,* 04-05 March 2016.

[167] J. Kang, Y. Chen, R. Yu, X. Zhang, H. Chen and L. Zhang, "Vertical Handoff in Vehicular Heterogeneous Networks Using Optimal Stopping Approach," *IEEE 8th International Conference on Communications and Networking in China (CHINACOM),* 2013.

[168] U. Kumaran and R. S. Shaji, "Vertical handover in Vehicular Ad-hoc Network using Multiple Parameters," *IEEE International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT),* 2014.

[169] S. Bi, C. Chen, R. Du and X. Guan, "Proper Handover between VANET and Cellular Network Improves Internet Access," *IEEE 80th Vehicular Technology Conference (VTC, Fall),* 2014.

[170] S. H. Ahmed, S. H. Bouk and D. Kim, "Reducing Scanning Latency in WiMAX Enabled VANETs," *Research in Adaptive and Convergent Systems Conference RACS'14,* Octorber 2014.

[171] R. I. Meneguette, L. F. Bittencourt and E. Madeira, "A Seamless Flow Mobility Management Architecture for Vehicular Communication Networks," *Journal of Communications and Networks,* vol. 15, no. 2, pp. 207-216, April 2013.

[172] J. M. Chung, M. Kim, Y. S. Park, M. Choi, S. Lee and H. Seo Oh, "Time Coordinated V2I Communications and Handover for WAVE Networks," *IEEE Journal On Selected Areas in Communications,* vol. 29, no. 3, 2011.

[173] K. L. Chiu, R. H. Hwang and Y. S. Chen, "Cross-Layer Design Vehicle-Aided Handover Scheme in VANETs," *Wireless Communications and Mobile Computing,* vol. 11, no. 7, pp. 916-928, July 2011.

[174] M. Gramaglia, C. Bernardos and M. Calderon, "Seamless internet 3G and opportunistic WLAN vehicular connectivity," *EURASIP Journal on Wireless Communications and Networking,* 2011.

[175] J. Dias, A. Cardote, F. Neves, S. Sargento and A. Oliveira, "Seamless Horizontal and Vertical Mobility in VANET," *IEEE Vehicular Networking Conference (VNC),* pp. 226-233, November 2012.

[176] R. S. Shukla and N. Tyagi, "Global Mobility and Handover Management for Heterogeneous Network in VANET," *International Journal of Next-Generation Networks (IJNGN),* vol. 5, no. 3, pp. 23-34, September 2013.

[177] P. Dahiya and S. Deswal, "Performance Analysis of Advanced FMIPv6 for Handover Management in VANET," *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET),* vol. 3, no. 6, pp. 13572-13578, June 2014.

[178] S. Joseph and R. Rajagopal, "Efficient Handoff Based Privacy Preservation for VANET," *International Journal of Science and Research (IJSR),* vol. 5, no. 3, pp. 1703-1708, 2016.

[179] S. Céspedes and X. S. Shen, "On Achieving Seamless IP Communications in Heterogeneous Vehicular Networks," *IEEE Transactions on intelligent transportation systems,* vol. 16, no. 6, pp. 3223-3237, December 2015.

[180] D. Mu, X. Ge and R. Chai, "Vertical Handoff Modeling and Simulation in VANET Scenarios," *IEEE International Conference on Wireless Communications and Signal Processing (WCSP),* 2013.

[181] A. Ghosh, V. V. Paranthaman, G. Mapp, O. Gemikonakli and J. Loo, "Enabling Seamless V2I Communications: Toward Developing Cooperative Automotive Applications in VANET Systems," *IEEE Communications Magazine,* pp. 80-86, December 2015.

[182] E. Gustafsson and A. Jonsson, "Always best connected," *IEEE Wireless Communications ,* vol. 10, no. 1, p. 49–55, 2003.