# Survey on Multi-hop Vehicular Ad Hoc Networks under IEEE 802.16 Technology

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## 1. Introduction

Today, there are many existing technologies designed to make vehicular road travel safer, easier and more enjoyable, using geographical positioning system, proximity sensors, multimedia communication, etc. The current data transmission requirements of these technologies, unfortunately, place great demand on both the algorithms and equipment, which often perform less than optimally, especially when having to interact with other vehicles. For example, GPS can trace a route to a specific location, but does so without taking into account some very important variables such as congestion caused by road conditions, high traffic volume and traffic accidents, which can entirely block one-lane traffic and affect two-lane traffic by almost 65% [1].

Presently, GPS permits users to obtain real-time location information. However, expanded communications among vehicles and with roadside infrastructure can substantially expand services drivers currently enjoy in the areas of traffic flow, safety, information (Internet), communications (VoIP) and comfort applications, among others [2].

According to Sichitiu et al. applications for vehicular communications include the following:

- Proactive safety applications: geared primarily to improve driver reaction and decision making to avoid possible accidents (e.g. broadcast warnings from a vehicle that has ignored red stop light) or minimize the impacts of an imminent crash (automated braking systems).

- Traffic management applications: mainly implemented to improve traffic flow and reduce travel time, which is particularly useful for emergency vehicles.

- Traffic coordination and traffic assistance: principally concerned with improving the distribution and flow of vehicles by helping drivers pass, change lanes, merge and form columns of vehicles that maintain constant relative speeds and distances (platooning).

- Traveler Information Support: mainly focused on providing specific information about available resources and assistance persons require, making their traveling experience less stressful and more efficient.

- Comfort Applications: primarily designed to improve the travel experience of the passengers and the driver (e.g. gaming, internet, automatic tolls, etc.)

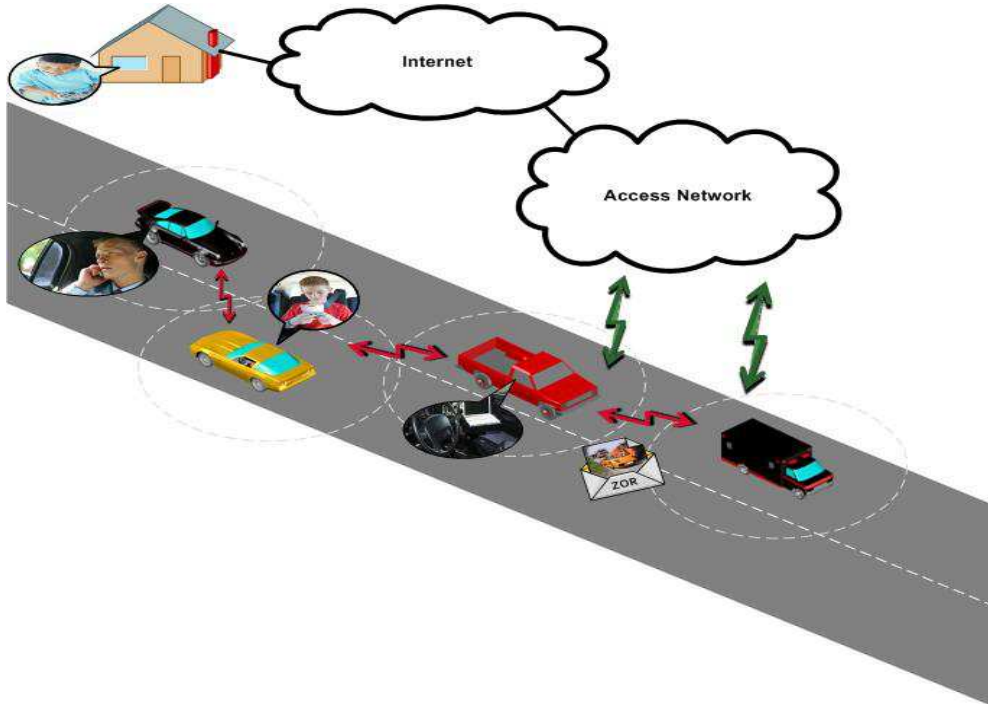Figure 1 shows some potential applications.



Fig. 1. Some potential services to be offered by vehicular communication networks

In order to provide greater passenger safety, convenience and comfort, protocols and equipment must provide more timely and reliable data transfer between network nodes for them to effectively share vital information. In the case of WiMAX, network nodes must efficiently transmit and receive data in a instantaneously changing network environment, characterized by the constant entry and exit of nodes. In addition, mobile nodes must handle handoffs between different clusters, all while functioning within very strict technical parameters regarding packet loss, delay, latency, and throughput, among others.

Sichitiu and Kihl in [3] construct a taxonomy based on the way nodes exchange data. Their work involves two forms of vehicular communication: vehicle to vehicle (IVC) and vehicle to roadside (RVC). IVC can employ either a one hop (SICV) or multi-hop (MIVC) strategy. On the other hand, RVC can be ubiquitous (URVC) or scarce (SRVC). Figure 2 schematizes these authors' taxonomy [3]. The following three figures explain this taxonomy and provide examples of IVC, RVC and HVC.

Communications within VANETs can be either inter-vehicular or vehicle to roadside and each type of communication imposes its specific requirements. For example, highway collision warning systems can more easily be implemented using multi-hop communications between vehicles (without infrastructure). On the other hand, traveller information requires fixed infrastructure to provide connectivity between the vehicles and
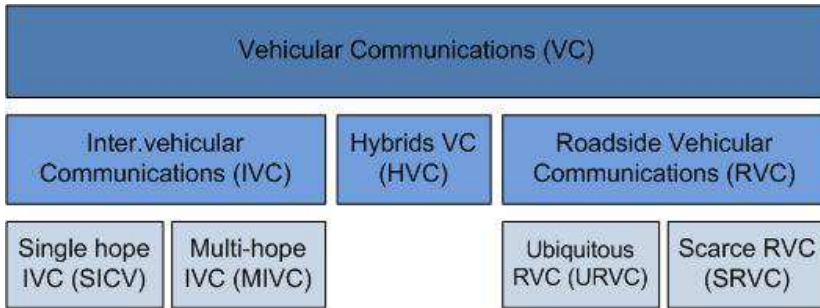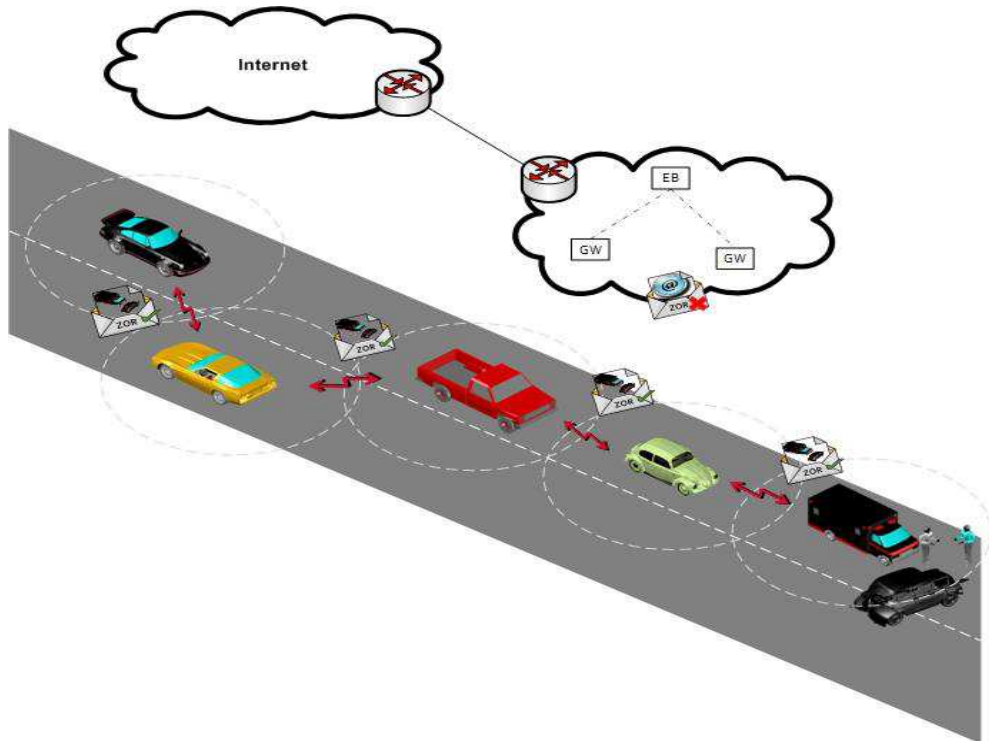
Fig. 2. Vehicular communications Taxonomy



Fig. 3. An IVC example

an information center. IVC deployment is significantly less expensive than RVC because it is infrastructureless. This kind of architecture allows vehicles to send information between each other via multi-hop communication, even with vehicles that are beyond their immediate radio coverage area. IVC internet access is much more complicated than with RVC. As a result, IVC can only provide a reduced number of applications. However, IVC is better suited for safety applications because the vehicles can almost immediately detect collision or congestion warning that is transmitted within the affected area. Figure 3 provides an example of inter vehicular communication, where a vehicle approaching an accident detects the crash and

informs the vehicles behind it that it is about to brake suddenly. This forewarning could help avoid other accidents caused by drivers who cannot apply their brakes opportunely and allows vehicles further behind to change lanes to lessen traffic congestion.

RVC can offer a wider range of applications because of its more stable and robust access to the Internet, which allows ready availability of information about specific places and the services they provide. RVC, however, has two important drawbacks when considered for safety applications:

- the cost of deployment of base stations (BS) makes it difficult to provide full coverage for so many vehicles over such a large area as vehicles leaving the BS coverage area lose connectivity.
- the delay caused by sending packets through a base station can prove disastrous in time sensitive safety applications.

Different technologies have been tested to enable RVC, including cellular, WiFi (IEEE 802.11p) and WiMAX (IEEE 802.16e), but no standard has been established as of yet. Presently, authors believe that WiMAX best fits VCN requirements because of its high bandwidth, robust medium access control (MAC), versatility (i.e. wide range of compatible standards) and QoS support. Importantly, it meets the already existing standard for mobile nodes (IEEE 802.16e). Figure 4 illustrates examples of some RVC applications, which include broadcasting the location of specific businesses and providing information about goods and services offered by them.
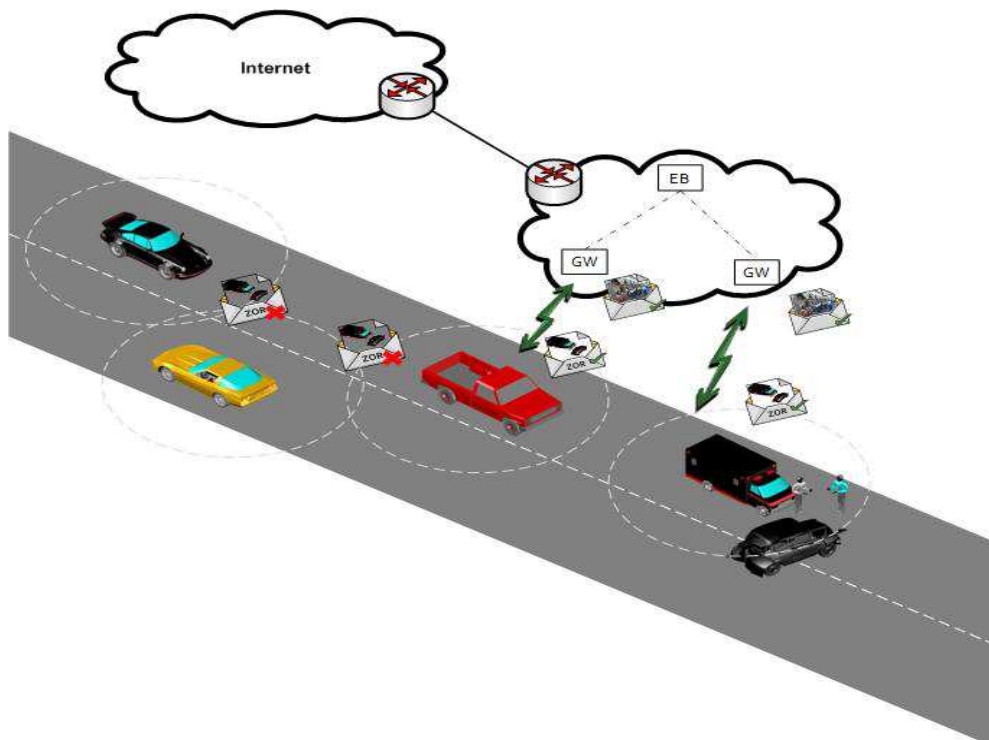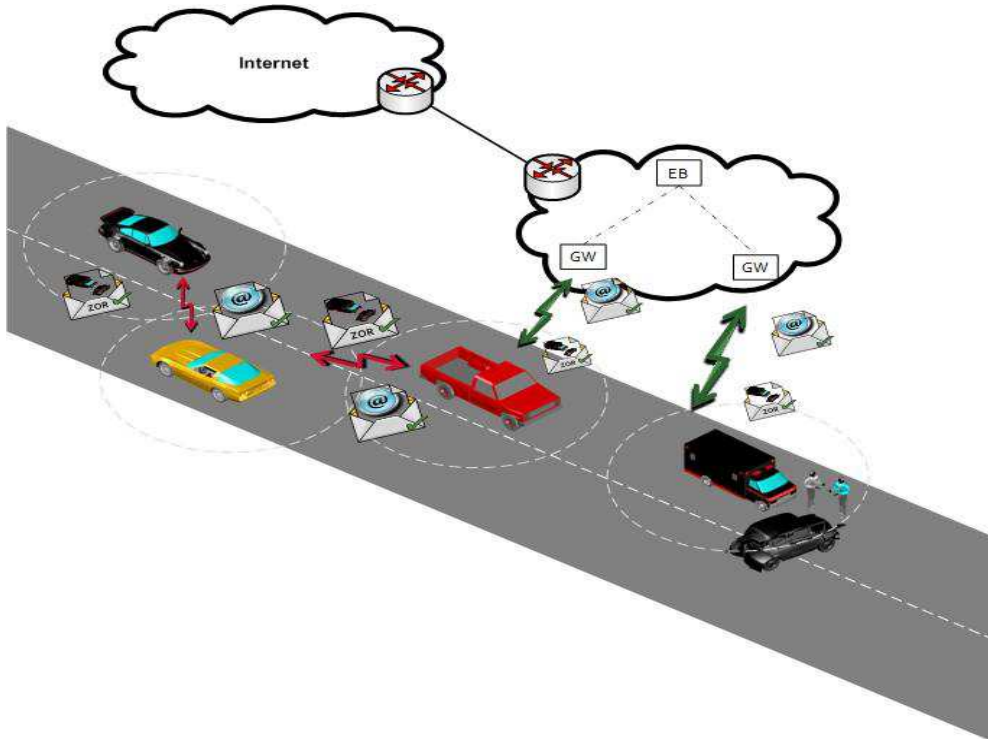


Fig. 4. A RVC network example

Fig. 5. A mixture of IVC and RVC (HVC)

Both IVC and RVC have desirable benefits; while with IVC users can form groups practically anywhere, with RVC persons can have access to internet and extend the vehicular applications. Importantly, combining both of these architectures into a hybrid vehicular communications (HVC) network can maximize benefits. HVC, however, is more complex in various aspects: HVC need more complex routing protocols, a robust physical layer and a medium access layer that is sufficiently dynamic to fully exploit the short duration of links and organized enough to minimize interference.

Figure 5 illustrates a hybrid vehicular communication network where vehicles inside the coverage area of a RVC can act as gateways for vehicles outside the coverage area. HVC networks are very desirables because they can provide virtually any kind of service. Importantly, however, as previously mentioned, research must first overcome many technical challenges before HVC networks can be implemented in real-world applications. This is primarily because of the incompatibility of technologies (e.g. WiFi was developed for WLANs, while cellular communications were designed for WANs).

As previously mentioned, each type of vehicular communications (IVC, RVC or HVC) has different technological requirements, although they all must meet several common demands inherent in VCN (see Table 1 and Figure 6). Three of these network requirements include [4]:

- radio transceiver technology that provides omni-directional coverage
- rapid vehicle-to-vehicle communications to keep track of dynamic topology changes
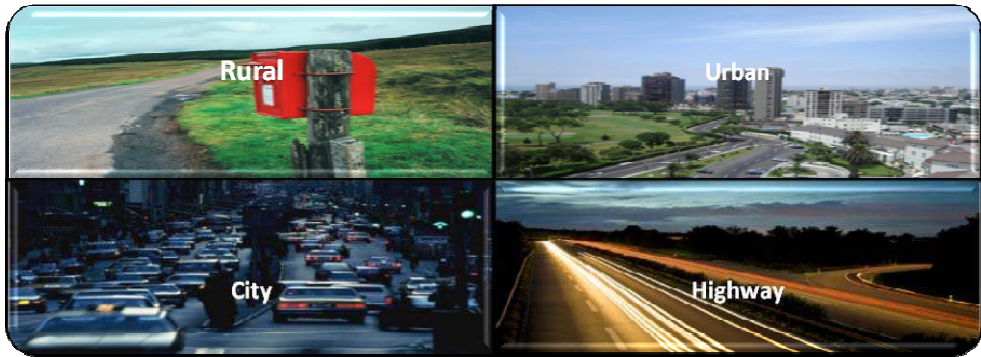- highly efficient routing algorithms that fully exploit network bandwidth

Fig. 1. Types of scenarios for VCN

|                  | Rural | Urban        | City         | Highway   |
|------------------|-------|--------------|--------------|-----------|
| **Speed**            | Low   | Medium/High  | Low/Very Low | Very high |
| **Vehicles Density** | Low   | Medium       | Very high    | Med/Low   |
| **Interference**     | Low   | Medium       | Very high    | Low       |
| **Infrastructure**   | Low   | Medium       | Very high    | Med/Low   |

Table 1. Features of Vehicular Scenarios

Numerous researchers have worked to overcome issues related to vehicular communications (e.g. [5-9, 10-12]). In 2004, the IEEE group created the IEEE 802.11p (wireless access in vehicular environments-WAVE) task force [13]. The workforce established a new standard that essentially employs the same PHY layer of the IEEE 802.11a standard, but uses a 10 MHz channel bandwidth instead of the 20 MHz used in IEEE 802.11a. With respect to the MAC layer, WAVE is based on a contention method (i.e. CSMA/CA), similar to other standards in this group.

The MAC layer in IEEE 802.11p has several significant drawbacks. For example, in vehicular scenarios, WAVE drops over 53% of packets sent according to simulation results [14].

WAVE also has a limited transmission range; simulations carried out by [15] show that only 1% of communication attempts at 750m are successful in a highway scenario presenting multipath shadowing. Furthermore, results in [16] show that throughput decays as the number of vehicles increases. In fact, throughput decreases to almost zero with 20 concurrent transmissions. The authors thus conclude that WAVE is not scalable. Additionally, IEEE 802.11p does not support QoS, which is essential in Vehicular Ad hoc Networks (VANETs). Importantly, safety applications using VCNs require not only expanded radio coverage, but also demand minimal delay, robust bandwidth, negligible packet loss and reduced jitter, among others (see Table 2).

Recently, the IEEE 802.16 taskforce [17, 18] actualized this standard to support QoS, mobility, and multihop relay communications. Networks using the IEEE 802.16 MAC layer now can potentially meet a wider range of demands, including VCN.

Worldwide Interoperability for Microwave Access (WiMAX) is a nonprofit consortium supported by over 400 companies dedicated to creating profiles based on the IEEE 802.16 standard.

| Application | Maximum Required Range (m) |
|---|:---:|
| **Approaching emergency vehicle warning** | ~1000 |
| **Emergency vehicle signal preemption** | ~1000 |
| **SOS services** | ~400 |
| **Postcrash Warning** | ~300 |

Table 2. Maximum required range for some applications in VCN

The first IEEE 802.16 standard considers fixed nodes with line of sight (LOS) between the base station and each fixed remote node [19]. Later, the IEEE 802.16 task force amended the original standard to provide mobility to end users (Mobile WiMAX[17]) in non-line-of-sight (NLOS) conditions. The most recent modification to IEEE 802.16e was in March, 2007, which later resulted in the IEEE802.16j multihop relay communications protocol, approved in 2009 [18].

IEEE 802.16j operates in both transparent and non-transparent modes. In transparent mode, mobile stations (MS) must decode the control messages relayed from the base station (BS). In other words, they must operate within the physical coverage radius of the BS because relay stations (RS) do not retransmit control information. In non-transparent mode, one of the RS provides the control messages to the MS. The main difference between transparent and non-transparent mode architecture is that in transparent mode, RS increase network capacity while in non-transparent mode, RS extend the BS range. Additionally, RS can be classified according to their mobility and can be fixed (FRS), nomadic (NRS) or mobile (MRS) [20].

Despite recent progress in implementing VCN with WiMAX, much work still has to be done. This work presents proposals that employ IEEE 802.16 as their underlying technology for multi-hop vehicular communication networks.

This paper is organized as follows: Section II analyzes various proposals suggested by researchers for VCN using WiMAX networks; Section III presents challenges of using WiMAX in VCN and Section IV presents conclusions.

## 2. State of the art of WiMAX in multi-hop vehicular communication networks

The authors in [21] propose a routing protocol called Coordinated External Peer Communications (CEPEC), whose cross-layer protocol is designed for multi-hop vehicular networks. They obtained their simulation results using a proprietary development tool which guaranteed all vehicles fair access to the Internet, even over nodes that were several hops distant from the BS. Their proposal includes organize the OSI model into three layers: PHY, MAC and Network. However, the authors do not specify the modifications they made to the IEEE 802.16-2004 standard that permitted the increased mobility and quicker registration of the MS. The authors employ TDMA to assign channels, exploiting TDMA's centralized scheduler and time division duplexing. Finally, and very importantly, CEPEC needs to determine the geographic position of every vehicle. To do this, all vehicles must be equipped with GPS.

An important disadvantage of CEPEC is that it only allows data communication from vehicles to the BS and vice versa; therefore, it does not provide for vehicle-to-vehicle data

exchange. Additionally, CEPEC's centralized scheduling mechanism reduces its scalability. Since, as previously mentioned, the authors of [21] do not specify the changes they made to the IEEE 802.16 standard, we must assume that vehicles enter the network according to standard specifications for nodes in mesh mode. Of course, this implies that network performance suffers significant deterioration. Also, the authors fail to detail the modifications they made to the standard that permitted increased mobility and topology control.

Figure 7 shows the segment configuration of a CEPEC simulation in which the green vehicles are segment subscriber stations (SSSs) and the red ones are segment heads (SH).
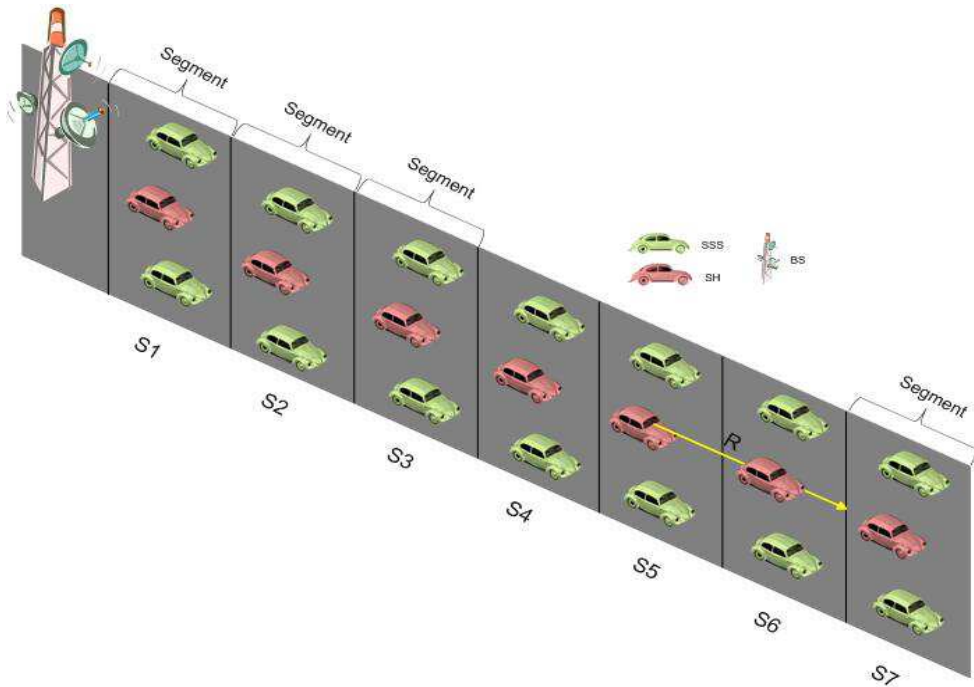


Fig. 7. CEPEC Topology

The authors in [22] do not provide simulation or test bed results and limit their work to making suggestions at a conceptual level about how to apply a hierarchical topology using WiFi hotspots (i.e. IEEE 802.11p) as access points for vehicles and WiMAX mesh stations as access points for WiFi hotspots. One major issue concerning this topology is that the IEEE 802.11p standard does not support QoS and the MAC contention-based method represents a significant disadvantage.

The topology in [22] is comprised of a point of access (PoA) consisting of a WiMAX mesh point (MP) and at least one access point (AP). The clusters are formed by several PoAs, one of which serves as a cluster head (CH) and domain, which is formed by a group of clusters. Figure 8 schematizes the described topology.

The authors in [23] propose a handoff mechanism called SWIFT, which includes modification in the MAC and network layers.
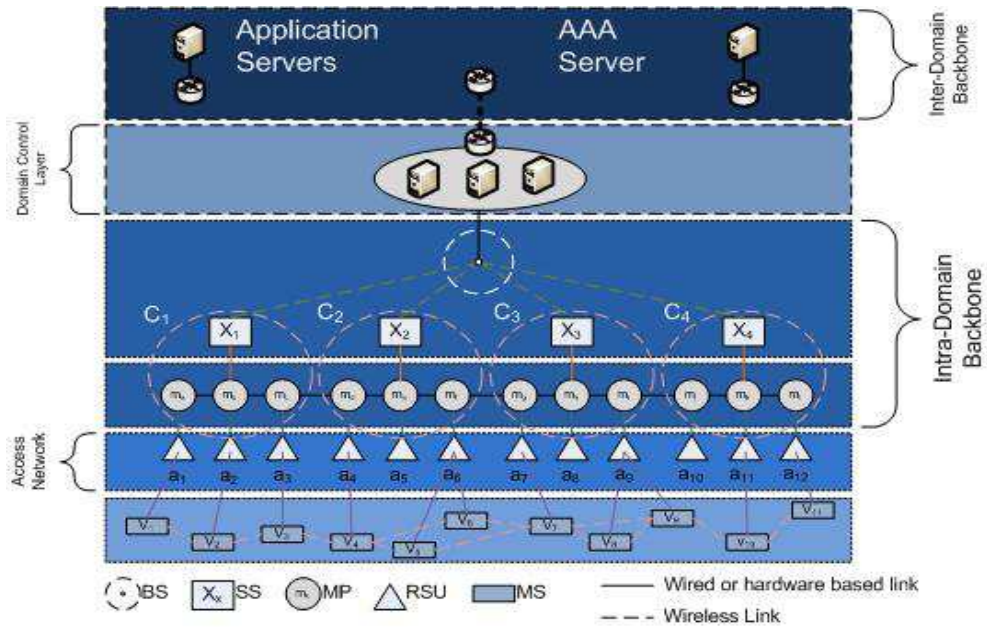
Fig. 8. Conceptual Architecture of [22]

The objective of the architecture is to provide high speed internet access in trains with a soft handoff, and having a minimum of connectivity interruptions. This proposal consists of a three layer topology: Level 0 is an access point functioning under the IEEE 802.11e standard; Level 1 uses base stations (BS) that work in conjunction with the IEEE 802.16m standard and Level 2 enables an optical backbone to interconnect with base stations located alongside the train tracks. Each train possesses two gateway interfaces that serve both as WLAN access points (i.e. IEEE 802.11e) and IEEE 802.16m subscriber stations. Results obtained using the popular NS-2 simulator show that the handoff latency of SWiFT is 52% less than with ipV6 mobile.

The SWiFT protocol can be seen as having a vehicle-to-roadside architecture where, as in [22], there is no possibility of inter-vehicular communications to cause a reduction in network services. Figure 9 shows the architecture of the SWiFT proposal.

In [24], the authors develop a handoff mechanism with a hybrid architecture using the IEEE 802.16e and IEEE 802.16j standards, which also includes control information of the vehicles via V2V. In this handoff mechanism, vehicles leaving their relay vehicle coverage area, called oncoming small size vehicles-OSV, directly transmit the information maintained in layers 2 and 3 to the vehicles outside the coverage area (called broken vehicles) of the relay vehicle. The information passed from OSV to BV is necessary to synchronize communications between the oncoming vehicle and the network.

The NS-2 simulator tool was used in this work and results show that the handoff mechanism developed helped reduce the handoff latency between relay vehicles. Figure 10 shows the topology described in [24] where the relay vehicles, in this case public buses, are equipped with IEEE 802.16j, which is used to register the buses at a base station that
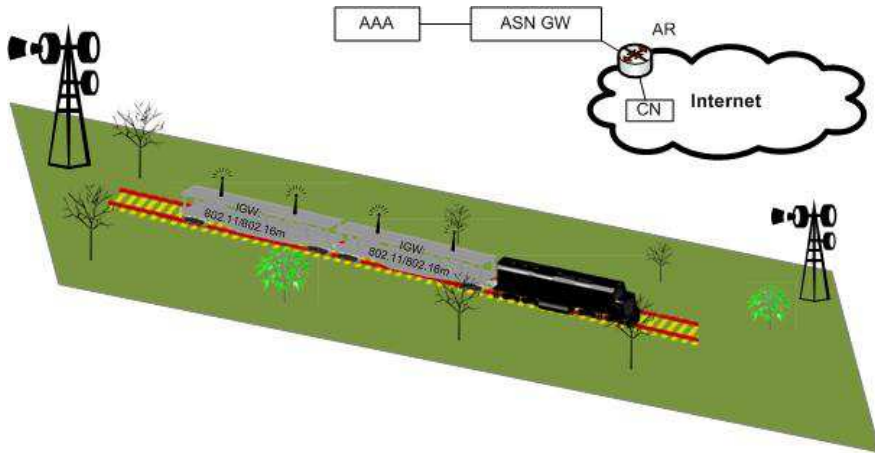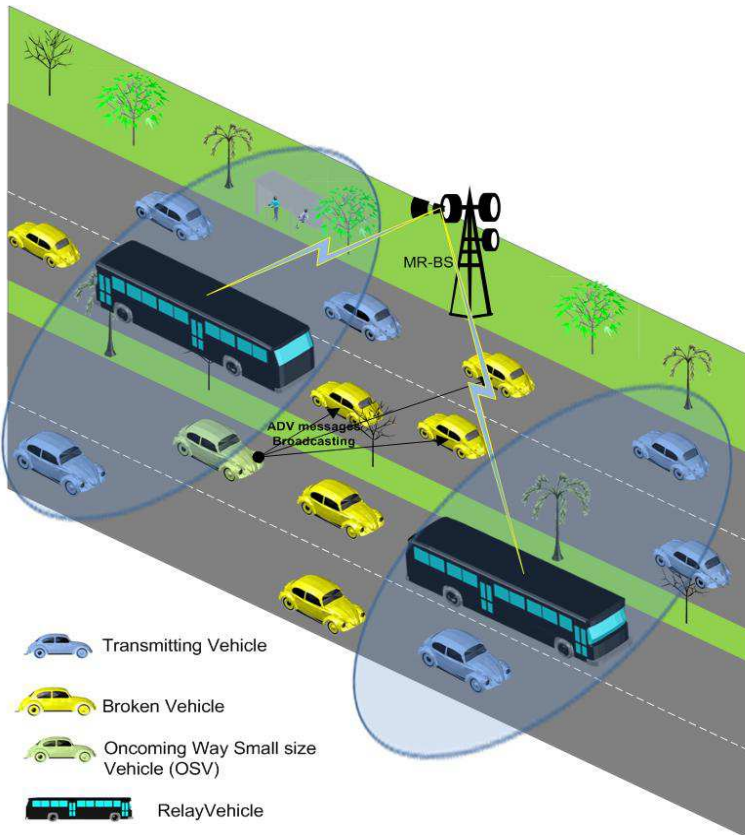
Fig. 9. SWiFT architecture
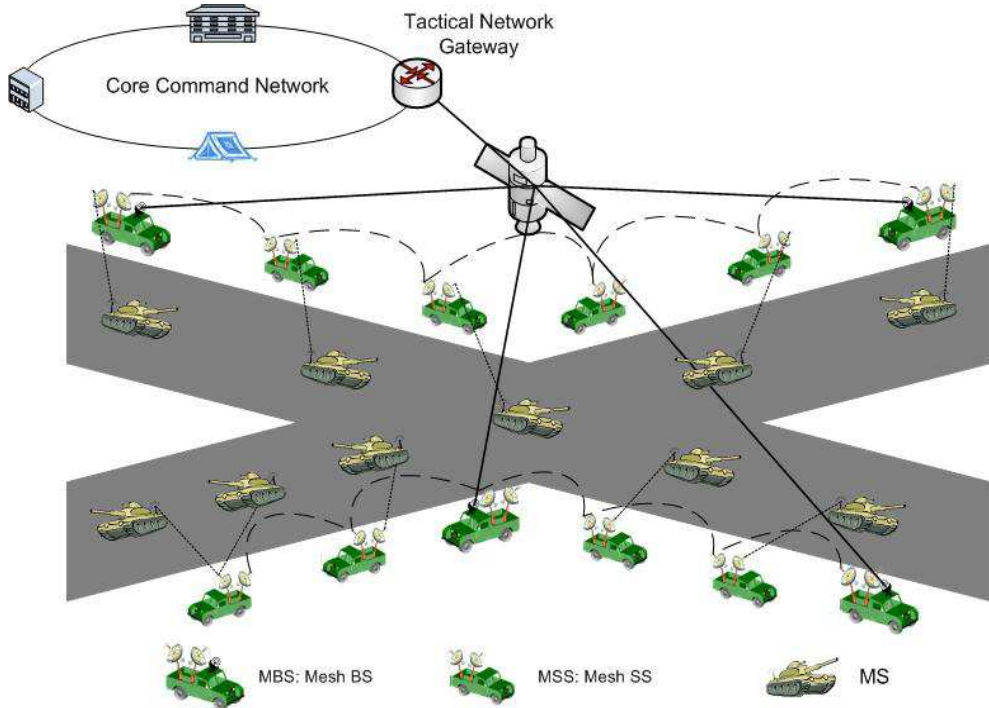


Fig. 10. A handoff with the VFHS mechanism.

Fig. 11. A possible network deployment using the scheduler mechanism proposed in [21].

functions according to IEEE 802.16e. This proposal does not provide a communications solution for vehicles beyond the RS or BS coverage. Additionally, it does not recommend a routing mechanism to assist nodes select the optimal RV for overlapping coverage areas.

The authors in [25] design a scheduling mechanism called "An interference and QOS aware distributed scheduling approach for hybrid IEEE 802.16e mesh networks," which was obtained using the NS-2 simulator. Their results show that the developed scheduling mechanism facilitates efficient spectral reuse by permitting the deployment of base stations under the IEEE 802.16-2004 mesh standard. Each BS also has an IEEE 802.16e interface that provides access to mobile subscribers. Importantly, the backbone is enabled by satellite communications and their proposal does not provide a routing mechanism to improve network performance. Finally, vehicles outside the coverage area of the BS cannot access network services. Figure 11 shows the topology suggested by [25].

The authors in [26] propose a routing mechanism for Mobile Ad-hoc networks (MANET). This mechanism uses a WiMAX architecture to relay routing information. After the route is enabled by a WiMAX BS, the data is sent through participating nodes.

The researchers in [26] implement their routing mechanism simulating speeds of up to 108 km/h. Their results show that packet delivery is good, but they do not mention the method used to combine the MANET and WiMAX architectures. Also, the simulations varied node

densities at a speed of 18 km/h, which is an insufficient velocity for their results to be conclusive. Another important issue concerns nodes leaving the BS coverage area, because network performance can be compromised by node mobility.

In [27], the authors use a roadside architecture based on IEEE 802.16j as shown in Figure 12. They suggest a method to select an optimal relay station. The method proposed is numerical and based on non-linear optimization. Their results show that network capacity can significantly increase; however, the authors do not validate their results via benchmarking or simulation.
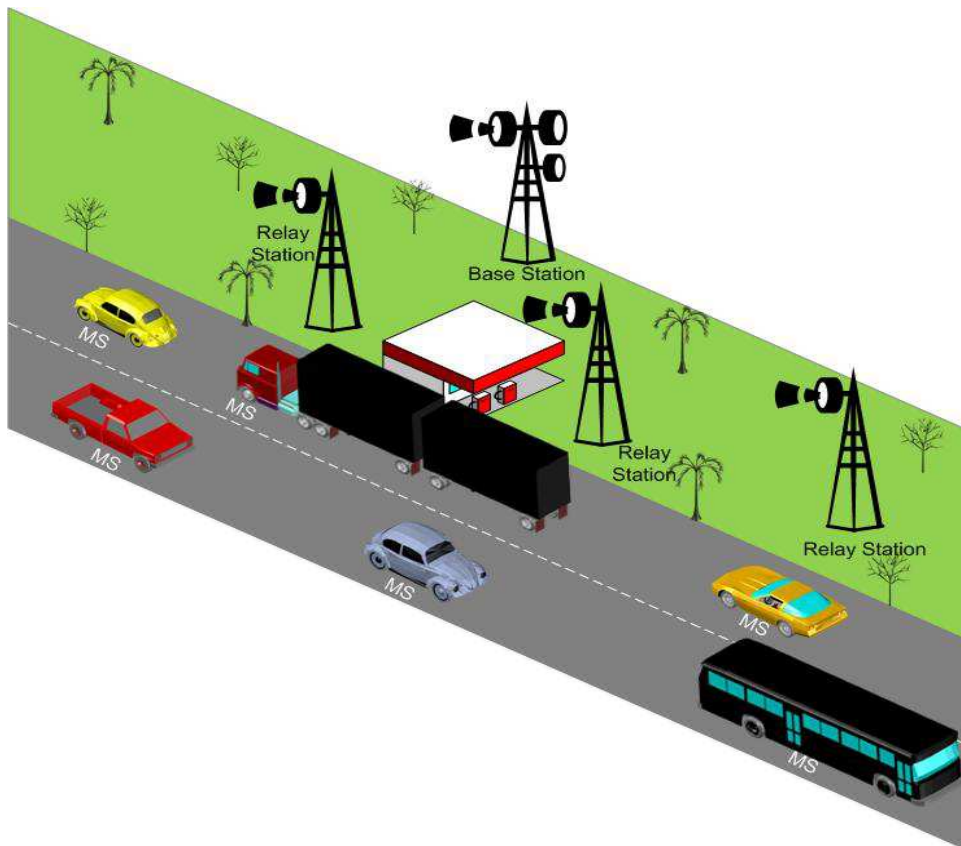


Fig. 12. Underlying Architecture with IEEE 802.16j for [27].

In [28], the authors propose a dynamic bandwidth allocation algorithm with a QoS guarantee for IEEE 802.16j-enabled vehicular networks. They suggest employing an optimization application that uses Lagrange multipliers. Their simulation results, obtained by Mathlab simulation, minimized queue delay and maximized network utilization. They assume that the primary link is the downlink and overlook that vehicular networks consist of both a downlink and uplink, both of which are equally important.

## 3. Actual challenges and conclusions

Although the proposals reported in this work show that WiMAX is suitable for multi-hop VCN because of its versatility and robustness in the physical and medium access layers, there still remain several technical challenges that must be overcome before deploying WiMAX as the underlying medium access and physical layer in VCN.

This current state of the art reveals that dynamic fully distributed routing mechanism which satisfies the demands of VCN, have not been proposed. Only the proposal by [21] includes a cross-layer hierarchical routing protocol; however, the scheduling mechanism is centralized and is based on the infrastructure, instead of a distributed algorithm. How to best permit intervehicular communication in VCN is still a contentious topic. Equally important are issues related to architecture; more precisely, how to form groups in the absence of the BS (ad-hoc domain) that can still interact with the BS upon demand. Equally important is how to provide control access in the boundaries of the coverage areas and determine which routing mechanism best optimizes network bandwidth. To the best of our knowledge, any proposal that involves WiMAX and VCN can form an ad-hoc domain without a BS or RS. The authors in [21] and [24] suggest a cooperative ad-hoc environment and infrastructure domain; however, the ad-hoc domain must exist with at least one node within the BS coverage area. Another important issue to be resolved is how to allocate bandwidth resource in ad-hoc networks while optimizing their performance. Research carried out by [25] and [28] provides a resource allocation mechanism for multi-hop networks; however, only in presence of a roadside BS.

## 4. Conclusions

The proposals analyzed in this work suggest that WiMAX can represent a viable alternative for roadside communication using present standards. Importantly, it also has the potential to be used in conjunction with radio technology for inter-vehicular communications because its strong PHY and QoS support. However, there are still significant technical challenges to be overcome before WiMAX can be implemented as radio technology for inter-vehicular communications networks.

Research provided in this chapter shows that integrating WiMAX technology into vehicular ad hoc networks is a very rich area of inquiry, although current research is somewhat limited. We believe that this is because standards for VCN are still in their infancy or have only very recently been published (i.e. IEEE 802.16j/June 2009, and IEEE 802.16m/February 2010[1]). Consequently, we predict there will be much more research carried out in the future as these standards are more fully exploited.

Table 3 shows the most outstanding features of the proposals included in this work [21-28].

| Ref | VRC | IVC | PHY | MAC | Red | Sim | 802.2 | App | Otras. Tec | Año |
|---|---|---|---|---|---|---|---|---|---|---|
| CEPEC | ✓ | ✓ | ✓ | ✓ | ✓ | Prop. | 2004 | Inter. | ⊘ | 2007 |
| Aspects of roadside backbone | ✓ | ✓ | ⊘ | ⊘ | ✓ | ⊘ | N/A | Back. | ⊘ | 2009 |
| SWIFT | ✓ | ⊘ | ⊘ | ✓ | ⊘ | NS2 | e,m | Inter. | IEEE 802.11e | 2008 |
| A cross layer Fast Handover | ✓ | ⊘ | ✓ | ✓ | ⊘ | NS2/NIST | e, j | Hand | ⊘ | 2009 |
| An interference and QoS aware distributed sched. | ✓ | ⊘ | ⊘ | ✓ | ✓ | NS2/NIST | E,2004 | Schd | ⊘ | 2008 |
| Position based conectionless | ⊘ | ✓ | ⊘ | ✓ | ✓ | NS2 | 2004 | Capa. | MANET | 2008 |
| Optimal Relay Selection in 16j MHR Vehicular Networks | ✓ | ⊘ | ⊘ | ✓ | ✓ | Mod. Mat. | j | Inter. | ⊘ | 2010 |
| Bandwidth Allocation Algorithm with QoS Guarantee for 16j vehicular Networks | ✓ | ⊘ | ⊘ | ✓ | ⊘ | Matl. | j | Inter. | ⊘ | 2009 |

*CEPEC, vehicle-to-vehicle exchange is for control packages only.

Table 3. Outstanding features of the proposals discussed in this paper.

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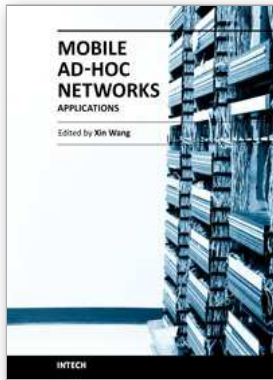
**Mobile Ad-Hoc Networks: Applications**

Edited by Prof. Xin Wang

Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: vehicular ad-hoc networks, security and caching, TCP in ad-hoc networks and emerging applications. It is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.

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