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Recent Progress and Challenges on Vehicular Mesh Networks: A Survey

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Abstract: The future mesh networks will not be limited to the indoor and outdoor networks. In the era of IoT, everything is connected to the network. The future of the mesh network will be defined as mesh network of moving things where each node of the mesh network have high speed mobility. Again they can easily join or leave the network without affecting the network. Here the high speed mobility nodes represent vehicles and communication between these vehicles in the form of mesh topology creates a Vehicular Mesh (VMesh). Here all the nodes work as a standalone Access Point (AP) which are well capable of receiving and transmitting data. This study discusses about the different protocols, research challenges and current ongoing research which will further help to explore the ways for new innovation for efficiency and betterment in the field of Vehicular Mesh Network (VMN).

Key words: IoT, VMesh, VMN, VANET (Vehicular Ad-hoc Network), nodes

INTRODUCTION

The future networks will not limited only to create networks inside a building or outside a building, rather it will have a whole city wide network with a very high speed data transfer capabilities. Although, the new generation is equipped with 4G technology but dependence on Wi-Fi can't be denied. Wi-Fi can provide reliable, faster and seamless internet connectivity (Carvalho, 2015). In this mobile era the expectation for getting Wi-Fi even on a high mobility is on high demand. In future, outdoor networks will be formed over the devices whose mobility will be very fast. In a network where nodes of high mobility will communicate with each other, it will need a vehicular mesh instead of a wireless mesh. In Vehicular Mesh Network (VMN), the mesh clients will be the vehicles with radio technology and these vehicles will use a mesh topology to form the mesh network. The mesh routers work like an intermediate node which receives and sends data traffic to other nodes which at last reaches to a gateway. In case of VMN every node have some routing intelligence. Again the gateways in VMN are also the moving gateways, i.e., some nodes work like gateways with mobility (Idrissi *et al*., 2015). These mobile gateways can connect to cloud or internet via a Road Side Unit (RSU) or directly to the internet using cellular network, i.e., 3G/4G.

The importance of the vehicular mesh network is increased in many folds in today's life. These networks can be created anywhere-anytime while vehicles on move without any pre-existing infrastructure. This will also helpful on the areas where it is hard-to-wire. Again using VMN, large scale coverage can be maintained. Like the mesh networks the vehicular mesh have some features as self-healing, resilient, extensible. Due to the VMN, the urban roads are becoming communication channels which are not confined only to ITS, other factors which increases the importance of the mesh network of the connected vehicles day by day is due to the high use of the fleet info, information collection or live data collection of a smart city such as traffic data, pollution data, weather information, etc. (Gerla and Kleinrock, 2011). Again this will lessen the burden of the cellular networks as the data traffic in this generation is much more than the voice traffic, getting internet through the Dedicated Short Range Communication (DSRC) which opens an area of research for the fast and seamless handoff between DSRC, Wi-Fi, 4G/LTE. The importance of the mesh network in this scenario is very high because it is robust.

The vehicular mesh has been used in many countries. One example of the vehicular mesh is the Veniam Project. The Veniam technology uses the concept of mesh of connected vehicles and they provide internet to the users

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throughout the city. They have implemented this project in the city of Porto and New York. In collaboration with the telecom giant Star-hub Veniam implemented this in the city of Singapore. A real large testbed "HarborNet" is also developed in the city of Porto where each moving container trucks, cranes, tow boats, patrol vessels and roadside units are connected to each other using this mesh network (Ameixieira *et al*., 2014).

The Vehicular Mesh Network (VNM) can be differentiated from a Vehicular Ad-hoc Network (VANET) by some advantages of VNM over VANET. The vehicular mesh is more structured than the VANET where each node is connected to every other node if they are in range. Earlier multihop routing protocols were not available over the VANET. The VNM is more reliable than the VANET as a link fails, the network automatically routes messages through alternate paths as they are designed to be self-configuring and self-correcting networks. VMN an emerging technology which will bring the dream into reality of seamless connected vehicles, using this lot of other challenges can be resolved. As the radio devices will be installed in most of the vehicles in future, the mesh network can easily formed to cover-up entire city using inexpensive, existing technology. In VMN hundreds of vehicles which are on move can talk to each other and also can share the connection throughout the city. The major challenges are need for research and innovation on more efficient underlying local mesh protocols for betterment. In this study some of the important protocols, usages and challenges are discussed.

VEHICULAR MESH ARCHITECTURE

Earlier, according to researchers by Nam *et al*. (2015) formation of vehicular for mesh network is the integration of two IEEE standards; 802.11p (protocol for VANET) and 802.11s (protocol wireless mesh network). Here the researchers called it ExWMN (Extended Wireless Mesh Network) for VANET. This mesh network formed over these two networks. The wireless mesh network can easily be formed by the RSU using 802.11s. Again other vehicles form a vehicular ad-hoc network which are also connected to the RSU. And the integration of these two is called the said network. Now 802.11p is much matured and lot of research went on 802.11p protocol. The V2I (Vehicle to Infrastructure) and V2V (Vehicle to Vehicle) communication technology well enriched to create a vehicular mesh network (Ameixieira *et al*., 2014). Nodes of a VNM consist of the following components. Mesh nodes are the clients of the mesh network. According to IEEE 802.11s standards the nodes are of two types; one is of mesh stations (STA) and others are Mesh Points (MP). The MP are capable of transmitting as well as receiving traffics. Again each MP can connect to internet. So sometimes MPs work like routers and gateways also (Chakraborty and Nandi, 2013) (Fig. 1). Those MPs work like Mesh Routers are also known as Mesh Access Point (MAP). MAP are responsible for forwarding traffic to and fro from STA to Mesh Portal Points (MPP) otherwise known as mesh gateways (Chakraborty and Nandi, 2013). In vehicular mesh each node works like a mesh

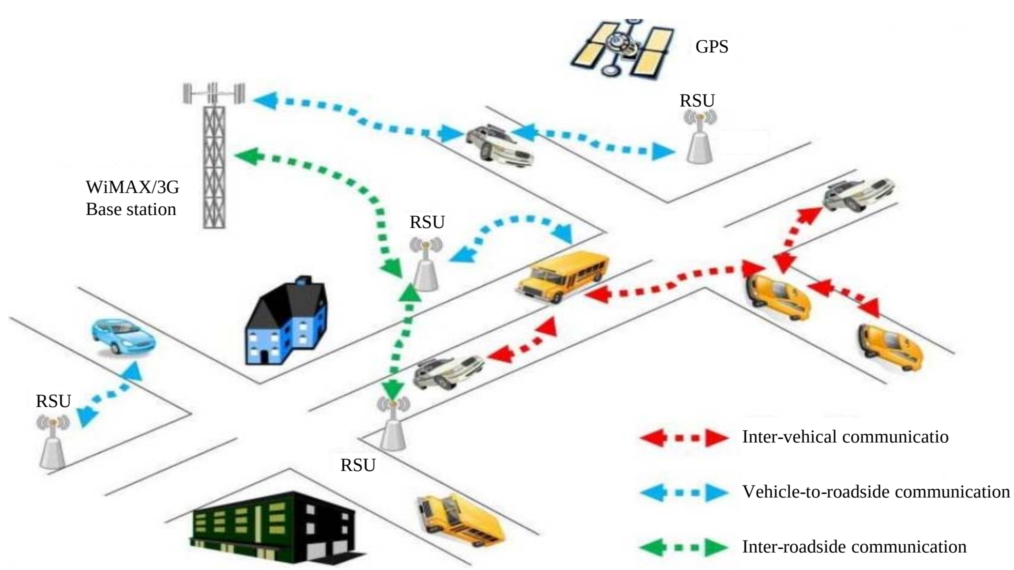

Fig. 1: Image for MP, MAP, MG

router as each of the vehicle are capable of transmitting data to and fro. Coming on Mesh Gateway, some MPs also work like mesh gateways. These are called Mesh Portal Points (MPP). They are capable to connect to internet or with other MPPs which are connected to the internet (Chakraborty and Nandi, 2013).

CHARACTERISTICS, APPLICATIONS AND LIMITATIONS OF VMN

Characteristics: The important characteristic of the vehicular network is the high speed mobility of the nodes (Oliveira *et al*., 2013). And this is the basic difference when we compare the vehicular mesh with the wireless mesh. The wireless mesh was designed for low mobility such as pedestrians or static users (Teixeira *et al*., 2014). As the vehicles on a high speed have less time to spend with RSU. So making these protocols use for high speed mobile vehicles, the protocols should be again re-designed for the routing, multicasting, mobility and QoS support (Doudane *et al*., 2012). Again, the network topology may change every moment due to the constant movement and with different speeds of the vehicles (Teixeira *et al*., 2014). The applications of vehicular network is increasing day by day. The VANET was primarily designed for the safety applications such as road safety message passing for the vehicles. Now, it also targets non-safety applications, transport efficiency applications and information/entertainment (infotainment) applications (Amadeo *et al*., 2012; Hossain *et al*., 2010). In future this will further extend to full support of vehicular internet.

The spectrum assigned by the FCC (Federal Communications Commission) of US is in 5.850-5.925 GHz frequency band for Dedicated Short Range Communications. This 75 MHz spectrum is divided in seven frequency channels of 10 MHz bandwidth each. The first channel is CH172 and the end channel is the CH184. The CH 178 is used as the Control Channel (CCH). This is a high priority channel. The research of the CCH is dedicated only for the safety relevant applications, system control and management. Other than the CCH there are six other channels used for supporting the non-safety applications and known as Service Channels (SCH) (Zang *et al*., 2007). The safety applications always follow the constraints like reliable communication with the minimal delay whereas the non-safety applications are more concern about the bandwidth rather than the delay. The importance of VMN comes to notice after the Zang *et al.* (2007) theoretically proved that VMesh MAC Protocol which they have proposed are more efficient over the WAVE MAC for the non-safety applications. They compared the result in better throughput. Furthermore the importance of vehicular mesh is increased as each vehicle is connected to other; so a broader network is achieved. Again using high range antennas with the IEEE 802.11-2012 standards protocol, the distance covered by the networks also increased up to 1000 m (Ahmed *et al.*, 2013).

Limitations: There are some limitations of the vehicular mesh also. These are very common as the wireless mesh networks suffers same problems which can be seen in the ad-hoc networks. Some of the very common limitations of the VMN is summarized here. Vehicles are at a higher mobility in the VMN. So, the connection time with other vehicular nodes is very less and it is also a difficult task. This affects Quality of Service (QoS). Performance of the network can be calculated by the end-to-end delay, packet loss, etc. This may lead to a delayed message passing system. But this delay tolerant networks can be taken as either sides, i.e., it can be taken as an advantage of this network. Bandwidth of the vehicular mesh is very important as this is very limited. So, in case of emergency other interfaces can be used to connect to the internet. Choosing a best interface at a particular time can be helpful but which is also a challenge itself. Movements of vehicles is fast, so a fast handoff techniques is also needed. The latency for handoff should be minimized otherwise it will only busy in handoff rather than transmitting data.

Maintaining routing tables in an ever changing nodes is also a very difficult task. So, efficient routing algorithms is needed. Here routing protocols should not flood the entire network in the shake of reliable message passing as the bandwidth is very limited. Again here WSMP (WAVE Short Message Protocol) comes into play because of this very smaller header size instead of the IPV6 header which is quite large. Security another challenging issue here. For safety message passing the security is the most vulnerable thing; where an innocent vehicle can intentionally have a rerouted message which may cause serious problem that can also lead to accidents, road jam, etc. (Bariah *et al.*, 2015).

PROTOCOLS, STANDARDS AND TECHNOLOGIES USED FOR VEHICULAR COMMUNICATION

There are various evolution on the different standards and protocols from the starting, very way back in October, 1999 when US Dept. of Transportation allocated 75 MHz of dedicated spectrum in the 5.9 GHz band to be used by Intelligent Transportation Systems (ITS) (DSRC: The future of safer driving; Dahlia and Raj (2014). Again in 2008 the European Telecommunications Standards Institute (ETSI, 2008) allocated 30 MHz of spectrum in the 5.9 Ghz band for ITS (Cars ‘Talking and Hearing in Harmony in 2008). Japan also allocated spectrum across from 5.8-5.9 GHZ band for the ITS (DSRC, 2001). WAVE and some other important

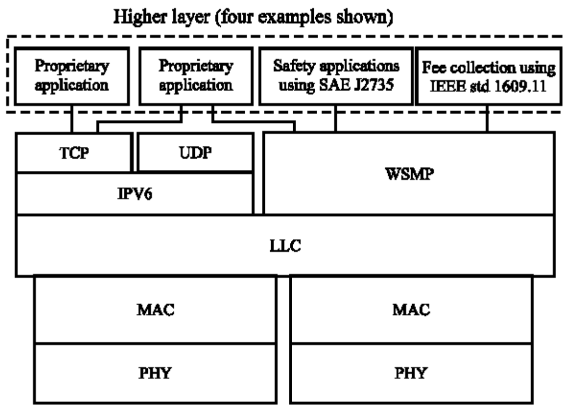

Fig. 2: Example of WAVE device configuration

protocols related to vehicular mesh network is described below along with addressing schemes used in WAVE.

WAVE: The IEEE1609 working group started WAVE for vehicular networks. The IEEE 1609.0 standard describes the basic architecture of the WAVE protocol. Complete WAVE device configuration in shown is Fig. 2. The WAVE protocol uses the 802.11p which is now incorporated in IEEE Standard 802.11-2012 protocol for the physical layer and mac layer. The IEEE 1609 standard used for security, network management and other layers from the WAVE protocol (Teixeira *et al*., 2014). The basic feature of WAVE is to provide high speed internet in wireless communication which is up to 27MB/s with a higher connectivity range around 1000 m and also promises a low latency in the vehicular communication (Ahmed *et al*., 2013; Eichler 2007; WAVE, 2011).

DSRC: It is a short or medium range wireless communication channel. DSRC is the origin for WAVE standard (Jiang and Delgrossi, 2008). Earlier it was used only for transmitting the emergency/safety messages so it was a one way channel. But now it is no more limited to that; so, it is now a two way or full duplex communication channel. The dedicated 75 MHz bandwidth spectrum for DSRC in the 5.85-5.925 GHz range is divided into 7 operation channels each of 10 MHz bandwidth (Ahmed *et al*., 2013; Jiang and Delgrossi, 2008).

802.11p: In the year 2004, IEEE 802.11 working group started to amend the 802.11 standard to include vehicular environment. Because the traditional radio channels are not suitable for the vehicular mesh networks. The traditional radios have long association time, sometimes because of high data losses communication becomes unstable (Teixeira *et al*., 2014). And it was result in 802.11p standard (Uzcategui and Acosta-Marum, 2009). Again this is a superseded IEEE standard which was used in VANET and it was replaced by IEEE 802.11-2012 Standard protocol.

802.21: This is the standard for the Media Independent Handoff (MIH). Otherwise known as vertical handoff. This has also some significance as the vehicles may not get some Wi-Fi unit then they have to check for some other means to transmit the emergency messages.

802.11s: This is the IEEE Standard for the Wireless Mesh Network (WMN). Here the communication network is consists of wireless nodes and they follow a mesh topology. Earlier the WNM was used for only static nodes. The concept of VMN comes into play when the nodes of WMN started moving with a high speed.

Addressing schemes in WAVE: The most common protocol stack is used in WAVE is the IPV6 as in near future the IPV4 is going to be exhausted. So, the IPV6 will be the most common addressing scheme in near future. The non-safety and proprietary applications use the UDP/TCP and IPV6 whereas the safety applications will use the WSMP (Li, 2012). The WSMP is proposed by the IEEE task group. This WSMP is the additional feature of the WAVE along with the regular IPV6 protocol which is dedicated for the WAVE protocol suite for safety applications (Tonguz and Boban, 2010). The low-latency, low-overhead and point to point traffic are the advantages of this new protocol stack (Uzcategui and Acosta-Marum, 2009).

WSMP: It is a special protocol which is developed only for the WAVE specific. This can carry message through the SCH and the CCH. The main advantages of the WSMP is that, this give permission to applications for direct control of the lower layer parameters such as transmit power, data rate, channel number and receiver MAC addresses. The main advantages of the WSMP is lower the latency and lower the overhead. One can figure-out the overhead by checking the WSMP packet, a 11 byte overhead which is much less than the UDP/IPV6 packet with the a minimal 52 byte overhead. The radio parameters are controlled by the WSMP by using the Transmission Power (TX), Data Rate and the Channel Number (Li, 2012).

RESEARCH CHALLENGES AND OPPORTUNITIES

Lot of challenging issues present in the vehicular mesh. Few major challenges on which thorough investigations are went and more research is needed. This study covers some of the major challenges among them. Again vehicular mesh can be used in many applications. The major use of vehicular mesh is in ITS and road safety applications. Now the trend of vehicular mesh used in different non-safety and infotainment applications. The research challenges can be divided in the following basis system based, application based, security based, mobility based.

System based challenges: In the vehicular mesh, the major system based challenges are load balancing, routing techniques.

Load balancing: Load balancing is one of the major issue present in the system based challenges. The load balancing can be used in many application such as in the gateway selection, routing, congestion control, etc. The gateway load should be distributed evenly among the gateways and they should not be overloaded so that the network will not suffer any packet drop because packet drop may hamper the reliability of network. Aljeri *et al.* (2013) and Idrissi *et al.* (2015) used load balancing in gateway selection which improved delivery ratio and throughput in high traffic loads. Some studys also used node load balancing as a major factor for routing which will ensure quick data delivery. Hashemi and Khorsandi (2012) and Togou *et al.* (2016) used load balancing in routing. Most of the research studys use greedy based algorithms for routing to reduce the end-to-end delay but Togou *et al.* (2016) use a stable Connected Dominating Sets (CDS) which they proved is better in minimizing the end-to-end delay.

Routing techniques: Different routing techniques used in VANET. Earlier the popular routing protocols which are used in the MANET that are adapted in VANET. The routing techniques which are implemented in VANET that can also be implemented in the vehicular mesh. The routing algorithms broadly divided for three types of communication scenarios. Vehicle to Vehicle (V2V) routing, Vehicle to Infrastructure (V2I) routing, Infrastructure to Infrastructure (I2I) (between RSU to RSU) routing. The routing techniques can be categorized by their nature or based on the topology. Proactive (Table Driven), Reactive (On demand), Hybrid (both proactive and reactive) (Ayaida *et al*., 2014; Sharef *et al*., 2014).

Vehicle to vehicle routing and vehicle to infrastructure routing has the major research challenges. The routing protocols on the V2V is further subcategorized; they are. Message casting based, delay based, position based, cluster based (Ayaida *et al*., 2014; Kumari and Shylaja, 2017; Sharef *et al*., 2014; Wang and Lin, 2013).

The message casting based routing further divided into unicast routing protocols, multicast routing protocols, Broadcast routing protocols (Bernsen and Manivannan, 2009; Sharef *et al*., 2014). The delay based routing protocols can be subdivided into three categories delay based non-delay based, hybrid (both delay and non-delay) (Kumari and Shylaja, 2017).

Application based challenge: There are number of application based challenges are present. Such as parking spot allotment where parking space is allocated to the vehicles efficiently. The advantages of a parking area allotment is efficient searching time which saves fuel, helps in limiting the air pollution and congestion on the parking area. Packet delivery ratio in car parking should be efficient. Once a car is assigned a place for parking and while reaching there if another nearest parking slot is available then the new parking slot should be allowed instead of the old in dynamic time which work more efficiently and a better result will be produced. Thus, delay in message passing may affect the efficiency in parking slot allocation. Slot may be provided to any vehicle but that vehicle didn't get that message. So, that slot is empty and waiting for the particular vehicle and other vehicles are not getting a slot who are in the queue. Because that place logically unavailable which may lead to a congestion in the system. Chang *et al.* (2014) proposed a direction based recommendation algorithm to reduce the search time. The algorithm exchange information between vehicles and between vehicles and roadside sensors to determine and parking space for a vehicle and that information is passed to the driver. Other application based challenges are visibility enhancer, electronic toll payment, etc. apart from safety related applications like lane changing warning, collision warning, etc. But the emerging challenge on the VMN based on application is vehicular internet.

Vehicular internet: Internet changed the modern lifestyle and working style. Internet became an integral part of our day to day life. Everyone can access high speed internet through static nodes, i.e., at home or office. But getting high speed, reliable internet while on move is still a challenge, i.e. while driving. Using the vehicular internet the concept of office on move comes. Again the travel will be more pleasant due to the vehicular internet (Cheng *et al*., 2011). Benslimane *et al.* (2011) proposed a new gateway discovery algorithm which reduces the overhead of gateway and also helps in seamless handover. Overall, it results in increased packet delivery and decreased in terms of overhead and delay. In the research study, Amadeo *et al.* (2012) proposed an enhanced 802.11p/WAVE protocol which is W-HCF (WAVE-based Hybrid Coordination Function) protocol. This uses the vehicle's position in-order to improve performance in delay and loss. Researchers of (Benslimane *et al.*, 2011; Gerla and Kleinrock, 2011) both advocates the importance of mobile IP or the Unique ID in their research studys. Further, Gerla and Kleinrock (2011) also advocates for the seamless handover for the better result in the ubiquitous internet for vehicles on move.

Security based challenge: These challenges are very important in this scenario. As the growth of the VNM will be rampant in the near future which may lead the privacy and safety of the users into a compromised state. So providing security to its users is must. There are various types of security loopholes are present in VNM. One of them is blackhole security attack in the routing environment where one node of the VMN behaves maliciously and don't participate in the routing (Mishra and Gupta, 2013). In this kind of attacks the blackhole node receives packets being in the part of the network but don't further forward the packet or forward the packet to a non-existing node which leads to data loss. The researchers by Baiad *et al.* (2016), Tyagi and Dembla (2016) detects the blackhole attacks. Further Tyagi and Dembla (2016) prevent these attacks using the pseudo reply packet on AODV routing protocol.

Mobility based challenge: These challenges are also important in VMN. As the vehicles move on a high mobility there is a need of multiple network interface for seamless connectivity. So that at the time of emergency message dissemination it will act like reliable system. Again in the future where the VMN will be more in use; The use of VNM will also be used for accessing internet. To access internet through VNM seamlessly with a promised QoS there are lot of challenges present as the nodes of the VNM moves on high velocity. To achieve this seamless handoff is required between the multiple network interfaces. Again in the time of mobility when RSS value decreases, some other factors like noise and packet drop increases then the node try to handoff from one RSU to another, here again the need of an efficient handoff algorithm is required (Yang *et al.*, 2013; Zhang *et al.*, 2010). Chen *et al.* (2014) and Zhang *et al.* (2013) proposed NEMO for VANET which is based on the NEMO (Network Mobility) protocol (Devarapalli *et al.*, 2005) drafted by Internet Engineering Task Force (IETF). The handoff completes in two phases, MAC layer handoff and network layer handoff (Zhang *et al.*, 2010). In the MAC layer handoff, the nodes choose best AP on the basis of the signal strength.

CONCLUSION

Increasing demand of the vehicular mesh network in the day to day life is due to the wide use of VNM in numerous applications. These applications spread over various fields from safety to non-safety applications. As the demand increases the need of more research is growing bigger than ever before. The maturity of the 802.11p protocol which is now IEEE 802.11-2012 is enough for the V2V and V2I communication for creating a reliable vehicular mesh network (Ameixieira *et al.*, 2014). This study covers some of the important characteristics along with some of the basic protocols which are used in VNM. This study also discusses about some emerging challenges in VNM. In the future as the people spending more time on their vehicles, therefore VNM based applications will be on more use which will further extend to support in reliable high speed ubiquitous vehicular internet on move which demands for more research in this area.

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