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Communications in Vehicular Networks

Zaydoun Yahya Rawashdeh and Syed Masud Mahmud
Wayne State University, Detroit, Michigan,
USA

1. Introduction

Recent advances in wireless networks have led to the introduction of a new type of networks called Vehicular Networks. Vehicular Ad Hoc Network (VANET) is a form of Mobile Ad Hoc Networks (MANET). VANETs provide us with the infrastructure for developing new systems to enhance drivers' and passengers' safety and comfort. VANETs are distributed self organizing networks formed between moving vehicles equipped with wireless communication devices. This type of networks is developed as part of the Intelligent Transportation Systems (ITS) to bring significant improvement to the transportation systems performance. One of the main goals of the ITS is to improve safety on the roads, and reduce traffic congestion, waiting times, and fuel consumptions. The integration of the embedded computers, sensing devices, navigation systems (GPS), digital maps, and the wireless communication devices along with intelligent algorithms will help to develop numerous types of applications for the ITS to improve safety on the roads. The up to date information provided by the integration of all these systems helps drivers to acquire real-time information about road conditions allowing them to react on time. For example, warning messages sent by vehicles involved in an accident enhances traffic safety by helping the approaching drivers to take proper decisions before entering the crash dangerous zone (ElBatt et al., 2006) (Xu et al., 2007). And Information about the current transportation conditions facilitate driving by taking new routes in case of congestion, thus saving time and adjusting fuel consumption (Dashtinezhad et al., 2004) (Nadeem et al., 2004). In addition to safety concerns, VANET can also support other non-safety applications that require a Quality of Service (QoS) guarantee. This includes Multimedia (e.g., audio/video) and data (e.g., toll collection, internet access, weather/maps/ information) applications.

Vehicular networks are composed of mobile nodes, vehicles equipped with On Board Units (OBU), and stationary nodes called Road Side Units (RSU) attached to infrastructure that will be deployed along the roads. Both OBU and RSU devices have wireless/wired communications capabilities. OBUs communicate with each other and with the RSUs in ad hoc manner. There are mainly two types of communications scenarios in vehicular networks: Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R). The RSUs can also communicate with each other and with other networks like the internet as shown in Figure 1.

Vehicular Networks are expected to employ variety of advanced wireless technologies such as Dedicated Short Range Communications (DSRC), which is an enhanced version of the WiFi technology suitable for VANET environments. The DSRC is developed to support the data transfer in rapidly changing communication environments, like VANET, where time-critical responses and high data rates are required.
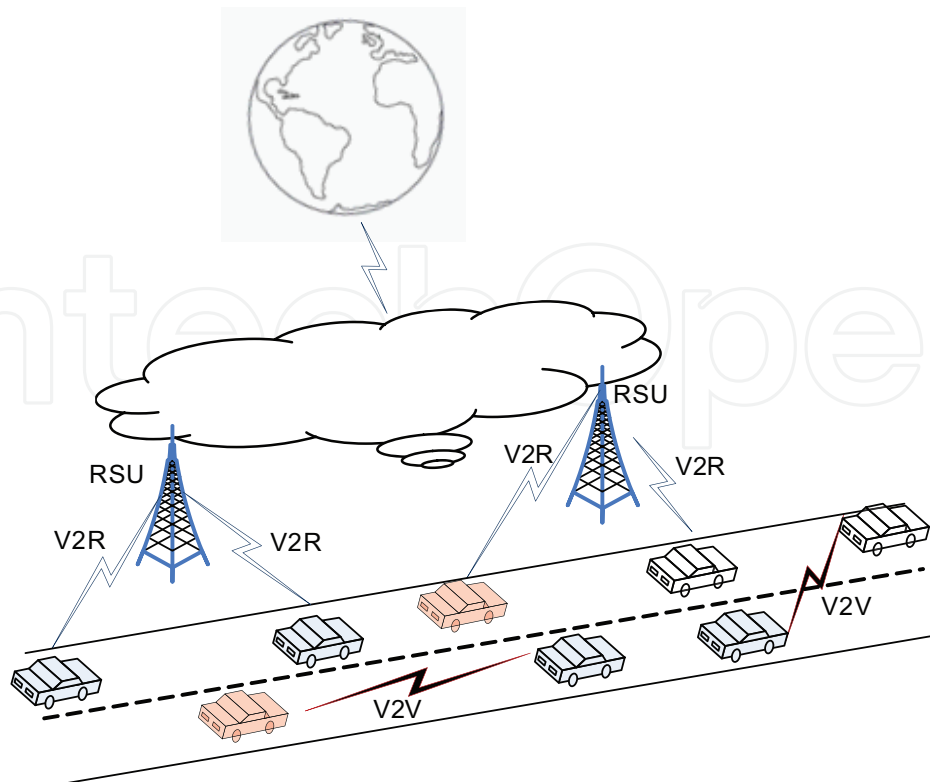
Fig. 1. VANET architecture

A number of technical challenges need to be addressed to make Vehicular networks more efficient to provide services to drivers and passengers (Torrent-Moreno et al., 2005). These challenges came from the unique features and characteristics (like frequent topology change, abundant of nodes, etc) of the vehicular networks. However, due to these unique characteristics, the standard MANET communication protocols are inefficient in the VANET environment. Therefore, the new communication mechanisms, like media access, data dissemination, routing, etc., designed for VANET should consider these unique characteristics to provide reliable communications. The Media Access Control (MAC) mechanisms should support fast link establishment and low latency communications to ensure the service reliability for safety applications considering the time constraints required by this type of applications. The data dissemination techniques should be designed to efficiently deliver the safety data to the intended receivers on time. Safety messages are of a broadcast nature targeting vehicles in a certain geographic area. Therefore, safety message dissemination mechanisms should deal with different types of network densities to eliminate the redundant rebroadcasted data, especially in very high network density scenarios. The frequent topology change characteristics pose another challenge for routing methods in VANET. In addition to the traditional routing challenges like broadcast problems, the VANET routing algorithms should be designed to ensure the quality and continuity of services for non-safety applications with high probability. Other challenges related to security and data managements should also be studied in depth in VANET.

The main objective of this book chapter is to introduce the reader to the main applications used in vehicular networks, the main characteristics of VANETs, and the challenges associated with the designing of new VANET communication protocols. All these will be covered in the context of the MAC, data dissemination, and routing mechanisms in VANET.

2. VANET characteristics and challenges

VANETs are characterized by their unique characteristics that distinguish them from MANET. These special characteristics can be summarized as follows:

1. **High mobility**: VANET nodes are characterized by their high relative speed which makes VANET environment high dynamic.
2. **Predictable and restricted mobility patterns**: Unlike the random mobility of MANET, VANET node movements are governed by restricted rules (traffic flow theory rules), which make them predictable at least on the short run.
3. **Rapid topology change**: VANET nodes are characterized by their high speed. This leads to frequent network topology changes, which introduces high communication overhead for exchanging new topology information.
4. **No power constraints**: Each vehicle is equipped with a battery that is used as an infinite power supply for all communications and computation tasks.
5. **Localization**: Vehicles can use the Global Positioning System (GPS) to identify their locations with high accuracy.
6. **Abundant network nodes**: Unlike MANETs that are characterized by a small network sizes, VANET networks can be very large due to high density of the vehicles.
7. **Hard delay constraints**: Safety messages are the main goal of VANETs. Therefore, safety messages should be given high priority and must be delivered on time.

The above unique characteristics create new challenges that need to be resolved in the vehicular network environments. According to (Torrent-Moreno et al., 2005), the main challenges of the vehicular networks can be summarized as follows:

- Frequent neighbourhood change due to high mobility.
- Increasing channel load (high density environment).
- Irregular connectivity due to the variation of the received signal power.
- Packet loss due to exposed and hidden terminal problems.

However, lots of efforts have been made to resolve these issues. The literature contains a huge amount of studies addressing these challenges in all aspects. The studies tried to address all layers related issues ranging from lower layers (physical and MAC layers) enhancement to upper layers (application) developments.

2.1 DSRC technology

DSRC is an emerging technology developed based on the WiFi standards. The DSRC technology will be used in the ITS domain to provide secure and reliable communication links among vehicles and between vehicles and infrastructure. These communication links allow the transfer of data that are necessary for the operation of different ITS applications. The DSRC is developed to work in very high dynamic networks to support fast link establishments and to minimize communication latency. Mainly, the DSRC is designed to ensure the service reliability for safety applications taking into account the time constraints for this type of applications. It can also support other non-safety applications that require a Quality of Service (QoS) guarantee. DSRC is developed for the environments where short time response (less than 50 msec.) and/or high data rates are required in high dynamic networks.

2.2 Characteristics of DSRC spectrum and data rates

In the United States, the Federal Communications Commission has allocated the 5.9 GHz Dedicated Short Range Communications (DSRC) (Xu et al., 2004) technique to support

public safety and commercial applications in V2V and V2R communication environments. The 5.9 GHz (5.850-5.925) band is divided into seven non-overlapping 10 MHz channels as shown in Figure. 2. One channel is called the control channel, and the other six are called service channels. The channels at the edges are reserved for future use. The control channel is used to broadcast safety data like warning messages to alert drivers of potential dangerous conditions. It can also be used to send advertisements about the available services, which can be transferred over the service channels. The service channels are used to exchange safety and non-safety data like announcements about the sales in nearby malls, video/audio download, digital maps, etc. Vehicles, using service channels, can relay the received data to other vehicles in other regions or/and to the roadside units.

The DSRC supports different data transfer rates: 6, 9, 12, 18, 24, and 27 Mbps with 10 MHz channels. The data rate can be increased to 54 Mbps with 20 MHz channels. Switching between the different data transfer rates can be achieved by changing the modulation schemes and channel code rate.
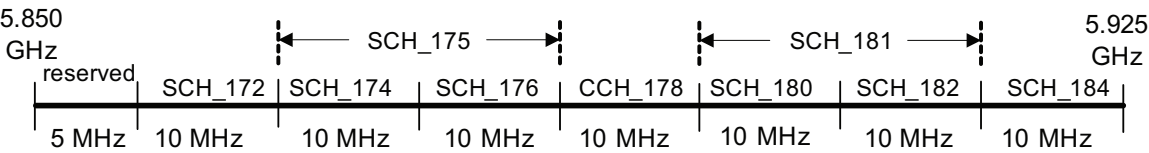

Fig. 2. DSRC channels

2.3 Applications and DSRC data traffic requirements

Numerous applications enabled by the DSRC technology have been proposed for VANET. These applications are categorized as Safety and Non-safety applications and installed on the OBUs and RSUs to process the safety and non-safety data. Different applications have different requirements. Safety messages are given higher priority over the non-safety data. Safety messages are time sensitive and should be disseminated to the vehicles in the surrounding area of the event within a bounded time. Safety messages are of a broadcast nature, therefore smart dissemination strategies should be employed to ensure the fast delivery of these messages. Safety messages in DSRC are either event-driven or periodic-based. For example, event-based safety messages are high priority messages generated and sent by vehicles involved in an accident to warn the vehicles approaching the accident area. On the other hand, periodic safety messages are considered preventive safety methods sent at specific intervals (e.g., every T second). The periodic messages carry the current status information like velocity, acceleration, direction, etc of the vehicles. These information are used by vehicles in the neighbourhood to update the status of their neighbouring vehicles. Periodic safety messages can also be sent by the RSU e.g., the RSU installed at the intersection periodically sends messages about the intersection conditions. The non-safety applications have different goals and can be used to provide a number of services ranging from transportation management, toll collection, infotainment, music download, to commercial advertisements. The non-safety data have low priority compared to the safety data. Table I shows requirements for various DSRC applications.

The DSRC also supports a number of different network protocols, which gives it the ability to interact with different types of networks. The DSRC supports the TCP/IP as well as IPv6 protocols. Thus, the internet applications/services can also be available in the VANET. Moreover, IP-based routing can also be enabled in VANET.

Applications	Packet Size (bytes)/ Bandwidth	Latency (ms)	Network Data Type	Application Range (m)	Priority
Intersection Collision Warning / Avoidance	~100	~100	Event	300	Safety of life
Cooperative Collision Warning	~100/ 10Kbps	~100	Periodic	50 - 300	Safety of life
Work Zone Warning	~100/ 1Kbps	~1000	Periodic	300	Safety
Transit Vehicle Signal Priority	~100	~1000	Event	300 - 1000	Safety
Toll Collections	~100	~50	Event	15	Non - Safety
Service Announcments	~100/ 2Kbps	~500	Periodic	0 - 90	Non - Safety
Movie Download (2 hours of MPEG 1)	>20 Mbps	NA	NA	0 - 90	Non - Safety

Table 1. DSRC Application Requirements (Xu et al., 2004)

2.4 VANET applications enabled by DSRC

In the context of the VANET applications, new types of applications enabled by the DSRC have been developed. These applications will benefit from the integration of different hardware components (CPUs, Wireless transceivers, Sensors, Navigations Systems, and input and output devices) that will be embedded in future vehicles. In the followings, we summarize some of the different VANET applications:

2.4.1 Safety applications:

The main goal of the safety applications is to increase public safety and protect the loss of life. The main characteristic of these applications is that the safety data should be delivered to the intended receivers (vehicles approaching the dangerous area) within a bounded time. The Vehicles Safety Communication (VSC) project has defined 34 different safety applications to work under the DSRC technology (Xu et al., 2004). These applications were studied in depth to determine the potential benefit provided by them. In the following, we present some of the applications that, according to the VSC, provide the greatest benefit in terms of safety of life.

2.4.1.1 Cooperative Collision Avoidance (CCA):

The main goal of this application is to prevent collisions. This type of safety applications will be triggered automatically when there is a possibility of collisions between vehicles. Vehicles, upon detecting a possible collision situation, send warning messages to alert the drivers approaching the collision area. The drivers can take the proper actions or the vehicle itself can stop or decrease the speed automatically. Another scenario where the CCA are of great importance is to avoid crashes during lane change. The CCA messages are disseminated to vehicles approaching the collision area. One of the proposed techniques to disseminate CCA messages on a highway was presented in (Biswas et al., 2006).

2.4.1.2 Emergency Warning Messages (EWM):

This type of applications is similar to the CCA. However, depending on the type of the emergency event, the EWMs either vanish once they are disseminated or may reside in the relevant area for longer period of time. For example, when vehicles detect an accident they start to send EWMs to warn vehicles that are close to the accident area. Another example is when vehicles sense a dangerous road conditions they send EWMs to other vehicles in a certain area, and these vehicles disseminate the EWMs to the new vehicles entering that area. Some of the proposed techniques are presented in (Yang et al., 2004) (Maih¨ofer, 2003) (Yu & Heijenk, 2008).

2.4.1.3 Cooperative Intersection Collision Avoidance (CICA):

This type of applications will be used to avoid collisions at the intersections (signalized or non-signalized). Mainly, an RSU installed at the intersection periodically distributes the state of the intersection to the approaching vehicles. The distributed information includes: 1) Traffic Signal State (e.g., red, green, yellow, and time remaining until the traffic switches to a new state). 2) State of the vehicles approaching the intersection that are within a relevant distance/time from the intersection (e.g. location, speed, and so on). 3) Intersection environmental conditions (e.g., weather, visibility, road surface at the intersection, and so on). Several of the works about the intersection collision avoidance can be found in (Tong et al., 2009) (Benmimoun et al., 2005).

2.4.2 Traffic managements:

This type of applications is used to facilitate traffic flow, thus reducing traffic congestion, fuel consumption, and travel time. This type of applications is less strict on real-time constraints. This means that if the messages are delayed, there is no real threat to life (no collision to occur), as opposed to the safety messages where a real threat to the life may occur if the messages are delayed. The information provided by these applications mainly describes the status of the traffic in a certain areas like intersection or road constructions. In this kind of applications, vehicles cooperate to generate messages;. These messages are aggregated and sent, using inter-vehicle communications, in a multi-hop manner to other vehicles in other geographic areas. Some of the papers that discuss the aggregation and forwarding are (Kihl et al., 2008).

2.4.3 Advertisements, entertainment and comfort applications:

The goal of this type of applications is to provide comfort and entertainments to the passengers. The advertisement applications have commercial purposes. The data of this type of applications should not consume the bandwidth on the count of the safety data. The priority should always be given to the safety data. Some of these applications are:

2.4.3.1 Electronic toll collection:

Using this service, the drivers don't need to stop and make the payment; instead the payment is done electronically through the network.

2.4.3.2 Entertainment Applications:

Multimedia files (music, movies, news, e-books, and so on) can be uploaded to vehicles. These data can also be transferred from one vehicle to another. Information about local

restaurants, hotels, malls, gas stations can be uploaded to the vehicles and can also be exchanged among vehicles using the inter-vehicular networks to facilitate travelling.

2.4.3.3 Internet Access:

Passengers can browse the internet and send/receive emails (Zhang et al., 2007). Most of these applications will be downloaded from other networks (like internet). However, vehicles use the inter-vehicle networks to distribute these information to reduce the cost associated with the installation of the infrastructure along the roads (Zhang et al., 2007) (Wang, 2007).

2.5 Wireless Access in Vehicular Environment (WAVE) stack

Lots of efforts have been made to design new standards for the services and the interfaces for VANET. These standards form the basis for wide range of applications in the vehicular network environments. Recently, a trial of a set of standardized services and interfaces defined under WAVE stack has been released. These services and interfaces cooperatively enable a secure V2V and V2R communications in a rapidly changing communications environment, where communications and transactions need to be completed in a short time frame. The WAVE architecture is developed based on the IEEE 802.11p and the IEEE P1609 standards (Nadeem, 2004). The IEEE 802.11p deals with the physical and Media Access Control layers, whereas the IEEE 1609 deals with the higher-layer protocols. In this section we try to give a background on these standards especially the MAC protocol.

2.5.1 The IEEE 1609 family of standards for WAVE

The IEEE has defined four standards and released them for a trial use (IEEE, 2007). Figure 3 shows the architecture of the WAVE family of standards, while Figure 4 shows the IEEE protocol architecture for vehicular communications (IEEE, 2007). These standards can be defined as follows:

2.5.1.1 IEEE 1609.1: Resource Manager

This standard defines the services and the interfaces of the WAVE Resource Manager applications. It describes the message formats and the response to those messages. It also describes data storage format that is used by applications to access other architectures.

2.5.1.2 IEEE 1609.2: Security Services

This standard defines security and secure message formatting and processing. It also defines how secure messages are exchanged.
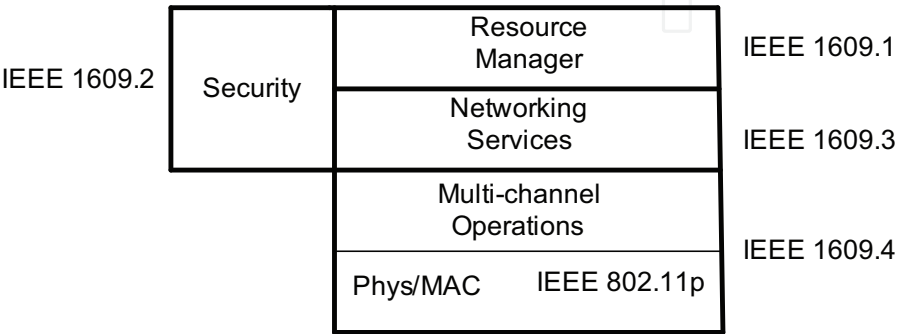

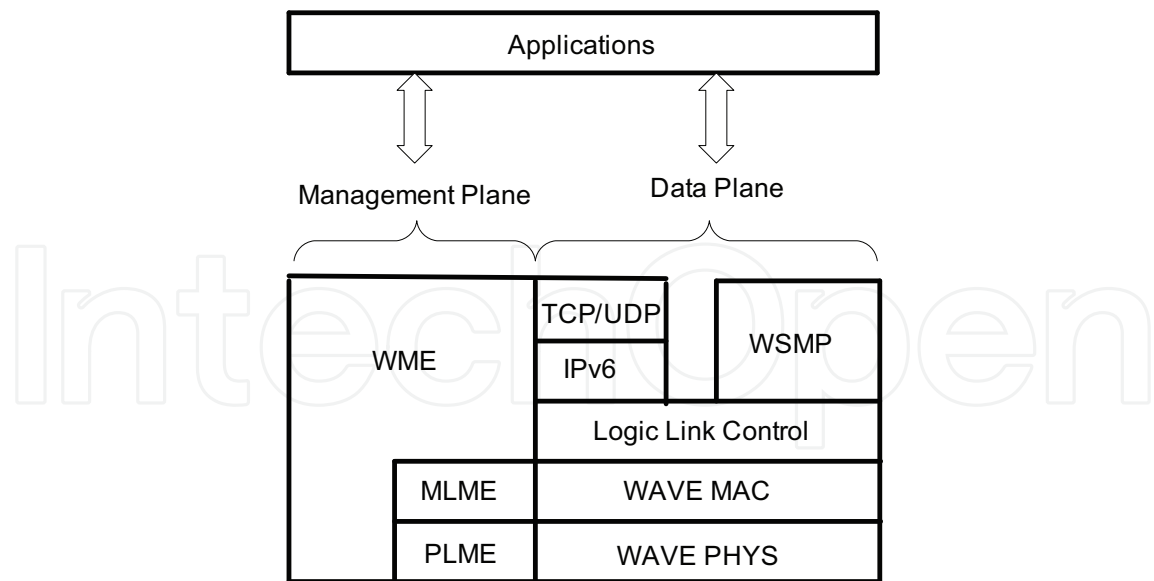Fig. 3. IEEE WAVE Stack for trial use

Fig. 4. IEEE protocol architecture for vehicular communications (IEEE, 2007).

2.5.1.3 IEEE 1609.3: Networking Services

This standard defines routing and transport layer services. It also defines a WAVE-specific messages alternative to IPv6 that can be supported by the applications. This standard also defines the Management Information Base (MIB) for the protocol stack.

2.5.1.4 IEEE 1609.4: Multi-Channel Operations

Multi-Channel Operations: This standard defines the specifications of the multi-channel in the DSRC. This is basically an enhancement to the IEEE 802.11a Media Access Control (MAC) standard.

2.5.2 The IEEE 802.11p MAC protocol for VANET

A new MAC protocol known as the IEEE 802.11p is used by the WAVE stack. The IEEE 802.11p basic MAC protocol is the same as IEEE 802.11 Distributed Coordination Function (DCF), which uses the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) method for accessing the shared medium. The IEEE 802.11p MAC extension layer is based on the IEEE 802.11e (IEEE, 2003) that uses the Enhanced Distributed Channel Access (EDCA) like Access Category (AC), virtual station, and Arbitration Inter-Frame Space (AIFS). Using EDCA, the Quality of Service (QoS) in the IEEE 802.11p can be obtained by classifying the data traffic into different classes with different priorities.

The basic communication modes in the IEEE 802.11p can be implemented either using broadcast, where the control channel (CCH) is used to broadcast safety critical and control messages to neighbouring vehicles, or using the multi-channel operation mode where the service channel (SCH) and the CCH are used. The later mode is called the WAVE Basic Service Set (WBSS). In the WBSS mode, stations (STAs) become members of the WBSS in one of two ways, a WBSS provider or a WBSS user. Stations in the WAVE move very fast and it's very important that these stations establish communications and start transmitting data very fast. Therefore, the WBSSs don't require MAC sub-layer authentication and association (IEEE, 2007). The provider forms a WBSS by broadcasting a WAVE Service advertisement (WSA) on the CCH. The WSA frame contains all information including the service channels

(SCH) that will be used for the next SCH interval. After receiving the WBS advertisement, the user joins the WBSS, and at the beginning of the next SCH interval, both the provider and the user switch to the chosen SCH to start data exchange. Since the provider and the user keep jumping between CCH and SCH, the provider can send a WSA frames during the CCH to let other users detect and join the WBSS. The users have the option to join the WBSS. The user can also receive other WBS frames while listening to the CCH to update the operational parameters of existing WBSSs. Once the provider and the user finish sending out all data frames, the provider ends the WBSS and the user also leaves the WBSS when no more data frames are received from the provider.

2.5.3 Media access control in VANET

Different MAC schemes targeting VANET have been proposed in the literature. Mainly, these schemes are classified as probability based and time based.

2.5.3.1 Probability-based MAC schemes

This type of media access control uses CSMA/CA technique to access the media. The advantage of this method is that vehicle movements don't cause any protocol reconfiguration. However, using this type of media access doesn't provide guarantee on a bounded access delay. Therefore, one of the main challenges of this method is to limit the access delay. The rest of this section presents a summary of three MAC schemes developed based on CSMA method.

The authors of (Zang et al., 2007) proposed a congestion detection and control architecture for VANET. The authors divided the messages into beacons (background data) having lower priority, and event driven alert messages with higher priority. One of the congested control methods is the adaptive QoS that deals with traffic of different types. The main goal of this work is to prevent the channel from being exhausted by the lower priority traffic (e.g., background beacon messages). The paper presented a congestion detection method called measurement based congestion detection, where nodes sense the usage level of the channel. The authors adopted a technique similar to the IEEE 802.11e to prioritize the traffic. In this technique the transmission queues are mapped to traffic with different priorities (access categories). The basic concept of the QoS adaptive method is to reserve a fraction of the bandwidth for safety applications. The authors defined three thresholds for the channel usage value.

1. If 95% of the total channel usage has been exceeded, then all output queues, except the safety message queue, are closed.
2. If 70% of the total channel usage has been exceeded, then the contention window size is doubled for all queues except for the safety message queue.
3. If the total channel usage becomes less the 30%, then the contention window of all queues is halved.

This work mainly uses the access category concept that is considered the core of the IEEE 802.11e. The work was implemented using one type of safety messages. It didn't show how to prioritize safety messages among themselves (which safety messages have higher priority than others when they attempt to access the media at the same time).

Another media access method called Distributed Fair Transmit Power Adjustment for Vehicular Ad hoc Networks (D-FPAV) was proposed in (Torrent-Moreno, 2006). The authors focused on adjusting the transmission power of periodic messages, and tried to keep the transmission power under a certain predefined threshold called Maximum

Beaconing Load (MBL). Thus, using this technique a certain amount of the overall bandwidth can be kept to handle unexpected situations. The authors tried to compromise between increasing the transmission power to ensure safety (increasing power means increasing transmission range, which means more receivers can be reached), and reducing it to avoid packet collisions. The authors used the centralized approach algorithm presented in (Moreno et al., 2005) to build the D-FPAV presented in (Torrent-Moreno, 2006). The algorithm in (Moreno et al., 2005) works as follows: every node in the network starts an initial minimum transmit power, then during every step, all nodes in the network start increasing their transmission power by an increment ε as long as MBL is not exceeded. Then, after this phase, each node finds the optimal transmit power value. Based on this, the authors proposed the D-FPAV that works for node u as follows:

- Based on the current state of the vehicles in the Carrier Sense (CS) range, use the FPAV to calculate the transmission power level P_i such that the MBL is not violated at any node.
- Send P_i to all vehicles in the transmit range.
- Receive messages and collect the power level calculated by all vehicles.
- Assign the final power level according to the following equation:

$$PA_i = \min\{P_i, min_{j:u_i \in CS_{MAx}(j)}\{P_j\}\} \tag{1}$$

Whereas $CS_{MAx}(j)$ is the carrier sense range of node j at the max power. The proposed work relies on adjusting the transmission power of the periodic messages. However, reducing the transmission power makes the coverage area small, which reduces the probability of receiving periodic messages by distant nodes.

In (Yang et al., 2005), the authors proposed a CSMA-based protocol, which gives different priority levels to different data types. The authors use different back-off time spacing (TBS) to allow the higher priority traffic to access the media faster than those with lower priorities. The TBS is inversely proportional to the priority such that high priority packets are given shorter back-off time before a channel access attempt is made. However, this type of prioritization mechanism was implemented in the IEEE 802.11e (IEEE, 2003). The paper also proposes another feature in which a receiving vehicle polls vehicles in its proximity. If a polled vehicle's data is ready for transmission, then the vehicle generates a tone indicating that state. Upon receiving the tone, the receiving vehicle clears it to transmit the packets (Yang et al., 2005). However, even with the use of busy tones, there is no upper bound on which channel access can take place.

2.5.3.2 Time-based MAC schemes

The time-based scheme is another approach to control the media access. In this approach, the time is divided into frames, which are divided into time slots. This approach is called Time Division Multiple Access (TDMA). The TDMA mechanism is a contention free method that relies on a slotted frame structure that allows high communication reliability, avoids the hidden terminal problem, and ensures, with high probability, the QoS of real-time applications. The TDMA technique can guarantee an upper limit on the message dissemination delay, the delay is deterministic (the access delay of messages is bounded) even in saturated environments. However, this technique needs a complex synchronization procedure (e.g., central point to distribute resources fairly among nodes). Some of the time-based methods use distributed TDMA for media access (Yu & Biswas, 2007), while most of

the others use centralized structure like the clustering techniques (Su & Zhang, 2007) (Rawashdeh & Mahmud, 2008). Some of the time-based approaches used in VANET are summarized as follows:

The authors of (Yu & Biswas, 2007) proposed a distributed TDMA approach called Vehicular Self-Organizing MAC (VeSOMAC) that doesn't need virtual schedulers such as leader vehicle. The time is divided into transmission slots of constant duration τ, and the frame is of duration T_{frame} sec. Each vehicle must send at least one packet per frame, which is necessary for time slot allocation. Vehicles use the bitmap vector included in the packet header for exchanging slot timing information. Each bit in the bitmap vector represents a single slot inside the frame (1 means the slot is in use, 0 means it's free). Vehicles continuously inform their one-hop neighbours about the slot occupied by their one-hop neighbours. Vehicles upon receiving the bitmap vector can detect the slot locations in the bitmap vector for their one-and two-hop neighbours, and based on this they can choose the transmission slots such that no two one-hop or two-hop neighbours' slot can overlap. The authors proposed an iterative approach, using acknowledgments through the bitmaps, to resolve the slot collision problem. The idea is to have each vehicle move its slot until no collision is detected. The vehicles detect the collision as follows: each vehicle upon joining the network marks its slot reservation and inform its neighbours. Upon receiving a packet from a neighbouring node, the vehicle looks at its time slot. If the time slot is marked, by the neighbouring node, as occupied, then the vehicle knows that the reservation was successful. If the time slot is marked as free, then this means a collision occurred and the reservation was not successful. However, this approach is inefficient when the number of the vehicles exceeds the number of time slots in a certain area.

In (Su & Zhang, 2007), the authors try to make best use of the DSRC channels by proposing a cluster-based multi-channel communication scheme. The proposed scheme integrates clustering with contention-free and/or -based MAC protocols. The authors assumed that each vehicle is equipped with two DSRC transceivers that can work simultaneously on two different channels. They also redefined the functionality of the DSRC channels. In their work, the time is divided into periods that are repeated every T msec. Each period is divided into two sub-periods to upload and exchange data with the cluster-head. After the cluster-head is elected by nearby nodes, the cluster-head uses one of its transceivers, using the contention free TDMA-based MAC protocol, to collect safety data from its cluster members during the first sub-period, and deliver safety messages as well as control packets to its cluster members in the second sub-period. The cluster-head uses the other transceiver to exchange the consolidated safety messages among nearby cluster-head vehicles via the contention-based MAC protocol. However, this method is based on the assumption that each vehicle is equipped with two transceivers. The authors also redefined the functionality of all DSRC channels such that each channel is used for a specific task.

In (Rawashdeh & Mahmud, 2008), the authors proposed a hybrid media access technique for cluster-based vehicular networks. The proposed method uses scheduled-based approach (TDMA) for intra-cluster communications and managements, and contention-based approach for inter-cluster communications, respectively. In the proposed scheme, the control channel (CTRL) is used to deliver safety data and advertisements to nearby clusters, and one service channel (SRV) is used to exchange safety and non- safety data within the cluster. The authors introduced the so called system cycle that is divided into Scheduled-Based (SBP) and Contention-Based (CBP) sub-periods and repeated every T msec. The system cycle is shared between the SRV channel and CTRL channels as shown in Figure. 5.

The SRV channel consists of Cluster Members Period (CMP) and Cluster Head Period (CHP). CMP is divided into time slots. Each time slot can be owned by only one cluster member. The end of the CHP period is followed by the CBP period during which CRL is used. At the beginning of each cycle, all vehicles switch to the SRV channel. During CMP, each cluster member uses its time slot to send its status, safety messages and advertisements. The CHP period follows the CMP and is allocated to the cluster-head to process all received messages and to respond to all cluster members' requests. Vehicles remain listening to the SRV channel until the end of the SBP. After that they have the option to stay on the SRV channel or to switch to any other service channel. By default, vehicles switch to the CTRL channel. Through analysis and simulation, the authors studied the delay of the safety messages. They focused on informing cluster members and informing neighbouring cluster members. The analysis showed that the maximum delay to inform cluster members is less than T, and to inform neighbouring cluster-members is less that 2T in the worst Case scenarios (depending on when the message is generated and when the message is sent). The authors showed the delay to deliver safety messages between two clusters.
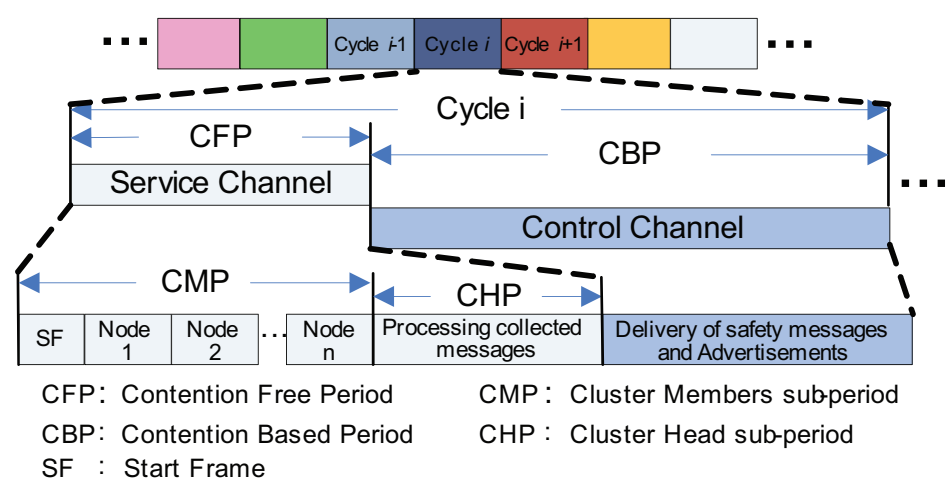

Fig. 5. System Cycle (Rawashdeh & Mahmud, 2008)

3. Data disseminations in VANET

In the context of the vehicular ad hoc networks data can be exchanged among vehicles to support safe and comfort driving. Several applications that rely on distributing data in a geographic region or over long distances have been developed. Different from routing that is concerned with the delivery of data packets from source to destination via multi-hop steps (intermediate nodes) over long distance, data dissemination refers to distributing information to all nodes in a certain geographic region. Its key focus is on conveying data related to safety applications particularly real-time collision avoidance and warning. While one of dissemination's main goals is to reduce the overload of the network; guaranteeing the exchange of information between all necessary recipients without noticeable delay, is also of great importance. Dissemination in VANET can also be seen as a type of controlled flooding in the network. Consider a scenario of a high density network, assume that vehicles detect an event and try to distribute the information about this event to other vehicles. The shared wireless channel will be overloaded when the number of forwarders that are trying to relay this data increases. Therefore, a smart forwarding strategy should be adopted to avoid

having the wireless channel congested. Moreover, safety messages are of a broadcast nature, and they should be available to all vehicles on time. Therefore, the dissemination techniques should minimize the number of unnecessary retransmissions to avoid overloading the channel. The data dissemination methods can be categorized as flooding-based where each node rebroadcasts the received message, and relay-based where smart flooding techniques are used to select a set of nodes to relay received messages.

3.1 Flooding-based method

Flooding is the process of diffusion the information generated and received by a node to other approaching vehicles. In this approach, each node participates in dissemination. The flooding can be suitable for delay sensitive applications and also for sparsely connected network. The main problem of this approach is that rebroadcasting each received message leads to network congestions, especially when the network is dense. The flooding of data is also limited by the ability of the system to handle properly new arrivals and dealing with the scalability issues (network size).

3.2 Relay-based method

In this approach, smart flooding algorithms are used to eliminate unnecessary data retransmissions. Instead of having all nodes disseminate the information to all neighbors, a relay node or a set of nodes are selected to forward the data packet further in an effort to maximize the number of reachable nodes. The relay-based methods have the ability to handle the scalability problem (increasing number of nodes in the network) of the high density nodes. However the main challenge of these approaches is how to select the suitable relaying node in the algorithm. Different algorithms were developed under the smart flooding techniques as follows: the time-based algorithms, the location-based algorithms.

3.2.1 Time-based algorithms

This type of dissemination algorithms is designed to eliminate unnecessary retransmissions caused by classical flooding. This mechanism gives the nodes that cover more area and maximizes the number of new receivers the chance (high priority) to forward the received message. In (Briesemeister, 2000), nodes calculate the distance between themselves and the sender of the message. If the message is received for the first time, each node sets a countdown timer and starts decrementing until a duplicate message is overheard or the timer is expired. The value of the timer is proportional to the distance from the sender. The higher the distance, the lower the timer value as shown in the following equation.

$$WT(d) = -\frac{MaxWT}{Range} \cdot \hat{d} + MaxWT$$

$$\hat{d} = \min\{d, Range\}$$

(2)

Where *Range* is the transmission range, *MaxWT* is the maximum waiting time, and $\hat{d}$ is the distance to the sender.

The node whose timer expires first (timer value reaches zero), forwards the received message. The other nodes, upon receiving the same message more than once, stop their countdown timer. The same process is repeated until the maximum number of forwarding hops is reached; in this case the packet is discarded.

3.2.2 Location-based algorithm

This approach relies on the location of the nodes with respect to the sender node. The node that reaches a large number of new receivers in the direction of the dissemination is selected to forward the messages. The goal is to reach as many new receivers as possible with less number of resources. The authors of (Korkmaz et al., 2004) proposed a new dissemination approach called Urban Multi-hop Broadcast for inter-vehicle communications systems (UMB). The algorithm is composed of two phases, the directional broadcast and the intersection broadcast. In this protocol, the road portion within the transmission range of the sender node is divided into segments of equal lengths. Only the road portion in the direction of the dissemination is divided into segments. The vehicle from the farthest segment is assigned the task of forwarding and acknowledging the broadcast without any apriori knowledge of the topology information. However, in dense scenarios more than one vehicle might exist in the farthest segment. In this case, the farthest segment is divided into sub-segments with smaller width, and a new iteration to select a vehicle in the farthest sub-segment begins. If these sub-segments are small and insufficient to pick only one vehicle, then the vehicles in the last subs-segment enter a random phase. When vehicles in the direction of the dissemination receive a request form the sender to forward the received data, each vehicle calculates its distance to the source node. Based on the distance, each vehicle sends a black-burst signal (jamming signal) in the Shortest Inter Frame Space (SIFS) period. The length of the black-burst signal is proportional to the distance from the sender. The equation below shows the length of the black-burst in the first iteration.

$$L_1 = \left\lfloor \frac{\hat{d}}{R} \cdot N_{max} \right\rfloor * SlotTime \tag{3}$$

Where L_1 is the length of the black-burst signal, $\hat{d}$ is the distance from the sender, R is the transmission range, N_{max} is the number of segments in the transmission range, and $SlotTime$ is the length of a time slot.

As shown in Equ. (3), the farther the node, the longer the black-burst signal period. Nodes, at the end of the black-burst signal, listen to the channel. If the channel is found empty, then they know that their black-burst signal was the longest, and thus, they are the suitable nodes to forward the message.

In the intersection phase, repeaters are assumed to be installed at the intersections to disseminate the packets in all directions. The node that is located inside the transmission range of the repeater sends the packet to the repeater and the repeater takes the responsibility of forwarding the packet further to its destination. To avoid looping between intersections, the UMB uses a caching mechanism. The vehicles and the repeaters record the ID's of the packets. The repeaters will not forward the packet if they have already received it. However, having the vehicle record the ID's of the packets will be associated with a high cost in terms of memory usage. Moreover, the packet might traverse the same road segment more than one time in some scenarios, which increases the bandwidth usage.

4. Routing in VANET

Routing is the process of forwarding data from source to destination via multi-hop steps. Specifically, routing protocols are responsible for determining how to relay the packet to its destination, how to adjust the path in case of failure, and how to log connectivity data. A

good routing protocol is one that is able to deliver a packet in a short amount of time, and consuming minimal bandwidth. Different from routing protocols implemented in MANETs, routing protocols in VANET environment must cope with the following challenges:

- Highly dynamic topology: VANETs are formed and sustained in an ad hoc manner with vehicles joining and leaving the network all the time, sometimes only being in the range for a few seconds.
- Network partitions: In rural areas traffic may become so sparse that networks separate creating partitions.
- Time sensitive transmissions: Safety warnings must be relayed as quickly as possible and must be given high priority over regular data.

Applying traditional MANET's routing protocols directly in the VANET environment is inefficient since these methods don't take VANET's characteristics into consideration. Therefore, modifying MANET routing protocols or developing new routing protocols specific for VANET are the practical approaches to efficiently use routing methods in VANET. One example of modifying MANET's protocols to work in the VANET environment is modifying the Ad hoc On Demand Distance Vector (AODV) with Preferred Group Broadcasting (PGB). On the other hand, new routing protocols were developed specifically for VANET (Lochert et al., 2003) (Lochert et al., 2005) (Tian et al., 2003) (Seet et al., 2004) (Tee & Lee, 2010). These protocols are position-based that take advantage of the knowledge of road maps and vehicle's current speed and position. Mainly, most of VANET's routing protocols can be split into two categories: topology-based routing and position-based routing. In the following sections, we will further define these two types of routing protocols. But, we will focus on the position-based type since it is more suitable for VANET environments.

4.1 Topology based routing

Topology-based routing protocols rely on the topology of the network. Most of the topology-based routing algorithms try to balance between being aware of the potential routes and keeping overhead at the minimum level. The overhead here refers to the bandwidth and computing time used to route a packet. Protocols that keep a table of information about neighbouring nodes are called proactive protocols; while reactive protocols route a packet on the fly.

4.1.1 Reactive topology based protocols

This type of protocols relies on flooding the network with query packets to find the path to the destination nodes. The Dynamic Source Routing (DSR) (Johnson & Maltz, 1996) is one of the reactive topology-based routing protocols. In the DSR, a node sends out a flood of query packets that are forwarded until they reach their destination. Each node along the path to the destination adds its address to the list of relay nodes carried in the packet. When the destination is reached, it responds to the source listing the path taken. After waiting a set amount of time, the source node then sends the packet from node to node along the shortest path.

The Ad Hoc On-Demand Distance Vector (AODV) (Perkins & Royer) is another reactive topology-based routing protocol developed for MANETs. The AODV routing protocol works similar to DSR in that when a packet must be sent routing requests flood the network, and the destination confirms a route. However unlike the DSR, in AODV the source node is

not aware of the exact path that the packet must take, the intermediate nodes store the connectivity information. AODV-PGB (Preferred Group Broadcasting) is a modified version of AODV that reduces overhead by only asking one member in a group to forward the routing query.

4.1.2 Proactive topology based protocols

This type of protocols builds routing tables based on the current connectivity information of the nodes. The nodes continuously try to keep up to date routing information. Proactive-topology based Routing protocols are developed to work in low mobility environments (like MANET). However, some of these protocols were modified to work in high mobility environment (Benzaid et al., 2002). In (Benzaid et al., 2002), the authors proposed a fast Optimized Link State Routing (OLSR), where nodes exchange the topology information using beacons to build routing paths. The exchange of beacon messages is optimized such that the frequency of sending these messages is adapted to the network dynamics. Mainly, the proactive routing protocols consume a considerable amount of bandwidth. This is because a large amount of data is exchanged for routing maintenance, especially in very high dynamic networks where the neighbourhood of nodes is always changing. The high dynamics of the network leads to frequent change in the neighbourhood, which increases the overhead needed to maintain the routing table, and consume more bandwidth.
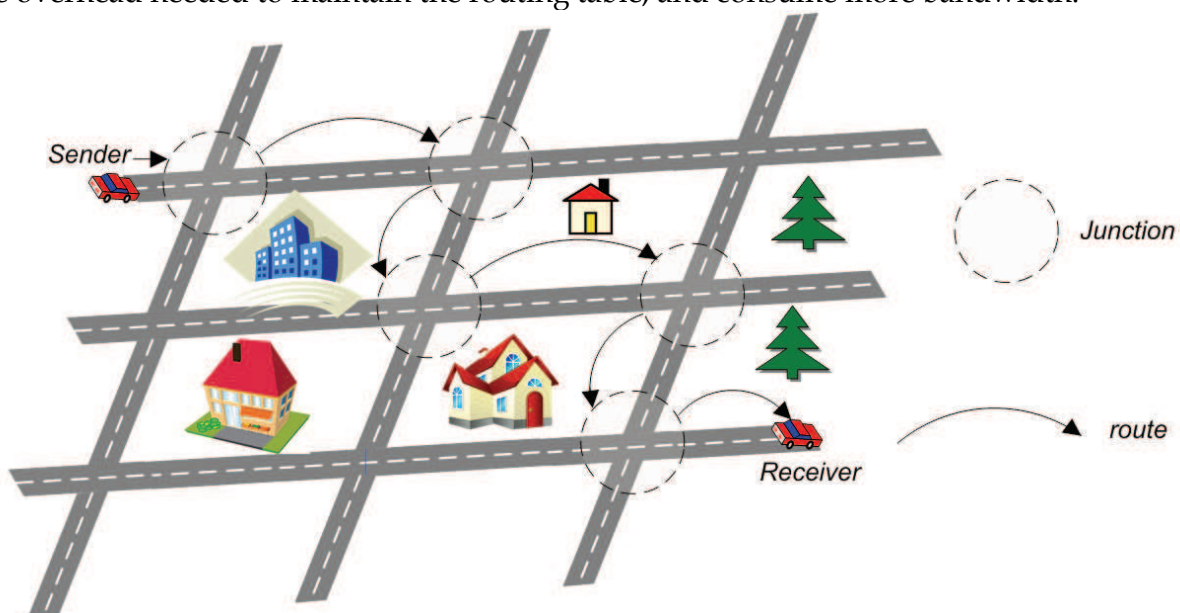

Fig. 6. Paths and junctions to route the packet

4.2 Position based routing

Position-based routing protocols or geographic routing protocols rely on the actual real world locations to determine the optimal path for a packet. The nodes are assumed to be equipped with device, like GPSs, allowing them to record their locations. Position-based protocols usually perform better in VANET than topology-based protocols because overhead is low, and node connectivity is so dynamic that sending a packet in the general direction of its destination is the most effective method.

In (Lochert et al., 2003), the authors proposed a position-based routing protocol for VANET called Geographic Source Routing (GSR). GSR relies on the maps of the cities and the

locations of the source and destination nodes. The nodes use Dijkstra's algorithm to compute the shortest path between source and destination nodes. In GSR, intersections can be seen as junctions that represent the path that packets have to pass through to reach their destination as shown in Figure 6. The GSR uses the greedy forwarding technique to determine the location of the next junctions on the path. The greedy destination is the location of the next junction on the path. A received packet is forwarded to the node that is closer to the next junction. This process is repeated until the packet is delivered to its final destination. Two approaches were proposed to deal with the sequence of junctions: the first approach requires that the whole list of junctions is included in the packet header. In this approach, the computation complexity and overhead is reduced, but bandwidth usage is increased. The second approach requires that each forwarding node computes the list of junctions. In this approach, bandwidth consumption is reduced, but computation overhead is increased. Finally, there are some issues that are not clear in GSR implementation, for example it is not clear how GSR deals with low connectivity scenarios and what happens when the forwarding node can't find another node closer to the next junction.

Lochert et al. (Lochert et al., 2005) proposed a position-based routing protocol suitable for urban scenarios. The routing protocols called Greedy Perimeter Coordinator Routing (GPCR). Similar to GSR, the proposed algorithm considers intersections as junctions and streets as paths. One of the main ideas implemented in the algorithm is restricted greedy forwarding. In the restricted greedy forwarding, the junctions play very important role in routing. Therefore, instead of forwarding packets as close as possible to the destination, restricted greedy routing forwards packets to a node in the junction as shown in Figure 7.
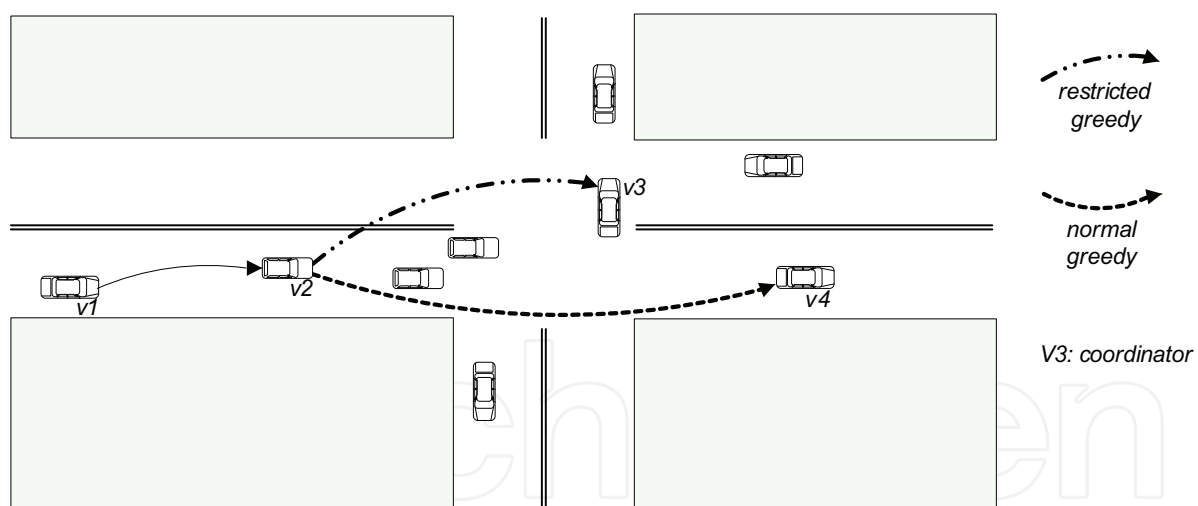

Fig. 7. Restricted greedy in GPCR

This is because the node on the junction has more options to route packets. In addition to that, the local optimum can be avoided (local optimum happens when a forwarding vehicle can't find a node closer to the destination than itself). The nodes close to the junction are called Coordinators. Coordinators announce their role via beacons to let neighbouring nodes know about them. Two approaches were proposed for the node to know whether its role is a coordinator or not. The first approach requires that nodes include their neighbours in the beacons, so that nodes can have information about their 2-hop neighbours. Based on this, the node is considered a coordinator if it has two neighbours that are within direct

communication range with respect to each other, but don't list each other as neighbours. This means that nodes are separated by obstacles. The second approach requires each node calculate the correlation coefficient with respect to its neighbours. Assume that x_i and y_i represent the coordinates for node i. Assume also that $\hat{x}$ and $\hat{y}$ are the means for x-coordinate and y-coordinate respectively. Let σ_{xy} represents the covariance of x and y, σ_x and σ_y indicate the standard deviation of x and y respectively. The correlation coefficient can be calculated as follows:

$$\sigma_{xy} = \left| \frac{\sigma_{xy}}{\sigma_x \sigma_x} \right| = \left| \frac{\sum_{i=1}^{n}(x_i - \hat{x})(y_i - \hat{y})}{\sqrt{(\sum_{i=1}^{n}(x_i - \hat{x}))^2(\sum_{i=1}^{n}(y_i - \hat{y}))^2}} \right| \qquad (4)$$

The value of σ_{xy} is in the range [0,1]. If the value is close to 1, then it indicates linear coherence, which is found when a vehicle is located in the middle of the street. A value close to 0 shows no linear relationship between the positions of the nodes indicating that a node is located on the junction. The authors used a threshold ϵ such that, if $\sigma_{xy} \geq \epsilon$ then the node is located on the street, and if $\sigma_{xy} < \epsilon$, then the node is close to the junction.

Packets are forwarded along the street. The farthest node is a candidate to forward the packets until they reach the intersection. Once a packet is delivered to a coordinator on the junction, a decision about which road the packet should traverse is made. Mainly, a neighbor that has the highest progress toward destination is selected.

The Spatially Aware Routing (SAR) (Tian et al., 2003) is a position based routing protocol that is more relevant to an urban setting. SAR takes into account that packets cannot be forwarded through the dense buildings in urban areas, so they must be forwarded through the streets and intersections (similar to GSR). SAR uses the maps of the cities such that the roads and intersections are represented as paths and junctions on a graph. The nodes select the junctions that the packet has to go through to reach its destination. Nodes use Dijkstra's algorithm to compute the shortest path on the graph. Then, this path is included in the header of the messages. The source node routes the packet using the shortest path algorithm on that graph. Upon receiving a packet, the forwarding node chooses the neighbor that is closer to the first junction in the GSR. The packet is forwarded to the next junction in the path until it gets delivered. The SAR algorithm uses different approaches to deal with the scenario when the forwarding node can't find another node closer to the next junction on the path. The first option is storing the packet and periodically trying to forward it. The packet will be discarded if the time limit is passed or the buffer becomes full. The second option is forwarding the packet, using the traditional greedy forwarding routing, toward the destination instead of the next junction. The third option is recalculating new path based on the current situation after discarding the path computed by the source node.

Anchor Based Street and Traffic Aware Routing (A-STAR) (Seet et al., 2004) is similar to SAR in that it also routes along streets and intersections. The packet is routed along a directional vector that contains anchors or fixed geographic points that the packet must go through. When A-STAR calculates the best path it prefers, streets with higher vehicle density, making the protocol traffic aware. Higher vehicle density in a street provides better transmission and less delay for a packet traveling along it. Traffic information is taken into consideration when the routing protocol uses the shortest path algorithm to determine the best path for the packet. Traffic information can be determined by the number of bus stops on a street, or by actual real-time measurements of traffic density. The first method is called

the statistically rated map and the second is called the dynamically rated map. A-STAR also has a novel way to deal with local maximums. When a packet reaches a void, the anchor path is recalculated and the surrounding nodes are notified that particular path is out of service.

Junction Based Adaptive Reactive Routing (JARR) (Tee & Lee, 2010) is a new routing protocol designed specifically to deal with urban environments. It uses different algorithms for when the packet is traveling to a junction, and when it has reached a junction. First the packet is forwarded down an optimal path to a junction. At that point a different algorithm takes over that determines the next optimal path and auxiliary routes. JARR takes into consideration velocity, direction, current position, and density when determining the path for a packet. In order for nodes to gather that information, a beacon regularly informs neighboring nodes of its position and velocity. JARR is able to reap the benefits of the beacon without paying the full price in overhead by adapting the frequency of the beacon as vehicle density increases. The higher the density, the less frequently the beacon is used to disseminate information. JARR also increases its throughput by allowing for some delay tolerance. For example, if a packet is transferred to a node that loses connectivity with the network, the packet will be carried until it can be forwarded.

5. Conclusion

This book chapter presented an overview and tutorial of various issues related to communications in vehicular networks. Various types of challenges in vehicular communications have been identified and addressed. A number of media access and routing techniques are also clearly presented. This book chapter will allow readers to get an understanding about what a vehicular network is and what type of challenges are associated with vehicular networks.
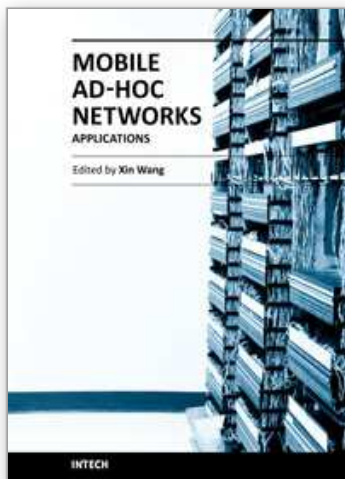
6. References

Benmimoun, A.; Chen, J.; Neunzig, D.; Suzuki, T. and Kato, Y. (2005). Communication-based intersection assistance, *Proceedings of the IEEE Intelligent Vehicle Symposium*, Las Vegas, NV, 2005.

Benzaid, M.; Minet, P. and Agha, K. (2002). Integrating fast mobility in the OLSR routing protocol, *Proceedings of IEEE Conference on Mobile and Wireless Communications Networks, Stockholm*, 2002.

Biswas, S.; Tachikou, R.; and Dion, F. (2006). Vehicle-to-Vehicle wireless communication protocols for enhancing highway traffic safety, *IEEE communications Magazine.* 44(1), 2006.

Briesemeister, Linda; Sch¨afers, Lorenz and Hommel, G¨unter (2000). Disseminating Messages among Highly Mobile Hosts based on Inter-Vehicle Communication., *Proceedings of the IEEE Intelligent Vehicles Symposium*, Detroit, USA 2000.

Clausen, T.; Jacquet, P.; Laouiti, A.; Muhlethaler, P.; Qayyum, A.; and Viennot, L. (2001). Optimized link state routing protocol, *Proceedings of IEEE International Multitopic Conference INMIC*, Pakistan, 28–30 December, 2001.

Dashtinezhad, S.; Nadeem, T.; Dorohonceanu, B.; Borcea, C. (2004); Kang, P.; Iftode, L.; TrafficView: A Driver Assistant Device for Traffic Monitoring based on Car-to-Car

Communication, *Proceedings of the IEEE Semiannual Vehicular Technology Conference*, Milan, Italy, May 2004.

ElBatt, T.; Goel, S. K.; Holland, G.; Krishnan, H.; Parikh, J. (2006). Cooperative collision warning using dedicated short range wireless communications, *Proceedings of ACM VANET* 2006, Page(s): 1-9

IEEE (2003). IEEE 802.11e/D4.4, Draft Supplement to Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), June 2003

IEEE (2007). IEEE Draft, "Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) — Architecture," P1609.0/D01, February 2007.

IEEE (2007). IEEE WG, IEEE 802.11p/D2.01, Draft Amendment to Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Wireless Access in Vehicular Environments, March 2007.

IEEE (2007). IEEE WG, IEEE 802.1lp/D2.01, Draft Amendement to Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Wireless Access in Vehicular Environments March 2007.

Johnson, D. B. and Maltz, D. A. (1996). Dynamic Source Routing in Ad Hoc Wireless Networks. In *Mobile Computing, T. Imielinski and H. Korth, Eds.*, Kluwer Academic Publisher, 1996, ch.5, pp. 153–81.

Kihl, M.; Sichitiu, M. and Joshi, H. P. (2008). Design and evaluation of two Geocast protocols for vehicular ad-hoc networks, *Journal of Internet Engineering* 2(1), 2008.

Korkmaz, G. et al. (2004). Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems, *Proceedings ACM Int'l. Wksp. Vehic. Ad Hoc Networks, Philadelphia*, PA, Oct. 2004.

Lochert, C.; Hartenstein, H.; Tian, J.; Fler, H.; Herrmann, D. and Mauve, M. (2003). A routing strategy for vehicular ad hoc networks in city environments, *Proceedings of IEEE Intelligent Vehicles Symposium*, Columbus, OH, 2003.

Lochert, C.; Mauve, M.; Fusler, H. and Hartenstein, H. (2005). Geographic routing in city scenarios, *ACM SIGMOBILE Mobile Computing and Communications Review*, 2005:69–72.

Maih¨ofer, C.; Cseh, C.; Franz, W.; and Eberhardt, R. (2003). Performance evaluation of stored geocast, *Proceedings of the IEEE 58th Vehicular Technology Conference*, Orlando, FL, 2003.

Moreno, T.; Santi, P.; and Hartnestien, H. (2005). Fair Sharing of Bandwidth in VANETS. *Proceedings of the 2nd ACM international workshop on Vehicular Ad Hoc Networks (VANET)*, pages 49-58, NewYork, USA, 2005.

Nadeem, T.; Dashtinezhad, S.; Liao, C.; Iftode, L. (2004) TrafficView: Traffic Data Dissemination using Car-to-Car Communication, *ACM Mobile Computing and Communications Review (MC2R)*, Vol. 8, No. 3, pp. 6-19, July 2004.

Perkins, C. E. and Royer, E. M. (1999). Ad-Hoc On-Demand Distance Vector Routing, *Proceedings of the IEEE WMCSA '99*, New Orleans, LA, Feb. 1999, pp. 90–100.

Rawashdeh, Z. Y. and Mahmud, S. M. (2008). Media Access Technique for Cluster-Based Vehicular Ad Hoc Networks, *Proceedings of the 2nd IEEE International Symposium on Wireless Vehicular Communications*, Calgary, Canada, September 21 - 22, 2008.

Seet, B. C.; Liu, G.; Lee, B. S.; Foh, C. H.; Wong, K. J. and Lee, K. K. (2004). A-STAR: A mobile ad hoc routing strategy for metropolis vehicular communications,

Proceedings of 3rd International Networking Conference IFIP-TC6 (IFIP '04), Athens, Greece, Dec 2004. Lecture Notes in Computer Science 3042:989–999.

Su, Hang and Zhang, Xi (2007). Clustering-based multichannel MAC protocols for QoS provisionings over vehicular ad hoc networks, *IEEE Transactions on Vehicular Technology* 56(6):3309–3323, November 2007.

Tee, C. A. T. H.; Lee, A. (2010). A novel routing protocol — Junction based Adaptive Reactive Routing (JARR) for VANET in city environments, *Proceeding of the 12th European Wireless Conference (EW 2010)*, vol., no., pp.1-6, 12-15, L ucca (Tuscany), Italy Apr. 2010.

Tian, J.; Han, L.; Rothermel, K.; and Cseh, C. (2003). Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks, *Proceedings of IEEE Intelligent Transportation System Conference (ITSC '03)*, Shanghai, China, October, 2003:1546–1551.

Tong, Zhu; Jian, Xu; Yu, Bai and Xiaoguang, Yang (2009). A research on risk assessment and warning strategy for intersection collision avoidance system, *Proceedings of the 12th Intelligent Transportations Systems*. (ITSC'09), pages 1-6, St. Louis, Missouri, U.S.A. 3-7 Oct. 2009.

Torrent-Moreno, M.; Santi, P.; and Hartenstien, H. (2005). The challenges of robust inter-vehicle communications, *Proceeding of IEEE 62nd Semiannual Vehicular Technology Conference*, VTC 2005-Fall, Dallas, Texas, Sep. 2005.

Torrent-Moreno, M.; Santi, P. and Hartnestien, H. (2006). Distributed Fair Transmit Power Adjustment for Vehicular Ad hoc Networks. *Proceedings of 3rd IEEE Sensor and Ad Hoc Communications and Networks*. SECON '06. Sep 2006.

Wang, S. Y. (2007). The potential of using inter-vehicle communication to extend the coverage area of roadside wireless access points on the highway, *Proceedings of the IEEE International Conference on Communications*, Glasgow, UK, 2007.

Xu, Q.; Mark, T.; Ko, J.; and Sengupta, R. (2004). Vehicle-to-Vehicle Safety Messaging in DSRC, *Proceedings of VANET*, October 2004.

Xu, Q.; Mark, T.; Ko, J.; Sengupta, R. (2007). Medium Access Control Protocol Design for Vehicle-Vehicle Safety Messages, *IEEE Transactions on Vehicular Technology*, Vol. 56, N. 2, pp.499-518, March 2007.

Yang, S.; Refai, H.; and Ma, X. (2005). CSMA based inter-vehicle communication using distributed and polling coordination, *Proceedings IEEE Int. Conf. on ITS*, Vienna, Austria, Sept. 2005, pp. 167-171.

Yang, X.; Liu, J.; Zhao, F.; and Vaidya, N. H.; (2004). A vehicle-to-vehicle communication protocol for cooperative collision warning, *Proceedings of the First Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*, Boston, MA, 2004.

Yu, B.; Gong, J.; and Xu, C.-Z. (2008). Catch-up: A data aggregation scheme for VANETs, *Proceedings of ACM VANET*, San Francisco, CA, Sep. 2008, pp. 49–57.

Yu, Fan F. and Biswas, S. (2007). A Self-Organizing MAC Protocol for DSRC based Vehicular Ad Hoc Networks, *ICDCS Workshops 2007*.

Yu, Q. and Heijenk, G. (2008). Abiding geocast for warning message dissemination in vehicular ad hoc networks, *Proceedings of the IEEE Vehicular Networks and Applications Workshop 2008*, 2008.

Zhang, Y.; Weiss, E.; Chen, L.; and Cheng, X. (2007). Opportunistic wireless internet access in vehicular environments using enhanced WAVE devices, *Proceedings of the International Conference on Future Generation Communication and Networking*, Jeju, South Korea, 2007.

Zang, Y.; Stibor, L.; Cheng, Xi; Reumerman, H.-J.; Paruzel, A. and Barroso, A. (2007). Congestion Control in Wireless Networks for Vehicular Safety Applications,. *Proceeding of the 8th European Wireless Conference*, Paris, France, Apr. 2007.

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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