Vehicular Ad Hoc/Sensor Networks in Smart Cities

Chao Song and Jie Wu

Abstract Smart city comprises numerous technologies and depends on sensors to be aware of its environment. Vehicular sensing where vehicles on the road continuously gather, process, and share location-relevant sensor data (e.g., road condition, traffic flow) is emerging as a new network paradigm for sensor information sharing in urban environments. In this chapter, we introduce the vehicular network and the challenges in it. We will briefly discuss the existing routing protocols for vehicular networks, and analyze them by a macro–micro model. In addition, we will also cover the vehicular sensor applications in smart cities.

1 Introduction

One way to cope with challenges of modern urban environment (increasing population, pollution, energy consumption, etc.) is by making it intelligent [1]. Smart cities take advantage of the benefits of integrating citizens and cities into the natural and ecologically friendly environment using modern technologies to improve their lives. Urban governance can be achieved through appropriate responses to events, redistribution of resources based on new environmental conditions, or any unnatural problems such as accidental or catastrophic benefits of modern technology. The city highly integrates the meaning of the road and vehicular traffic infrastructure with the networks themselves. Thus, along with standard infrastructures such as water supply or electricity, smart urban development is highly dependent on the development of transportation infrastructures on roads and streets as they are all potential locations for sensor and data transmission paths. In addition, modern vehicles that

C. Song
School of Computer Science and Engineering, University of Electronic Science and Technology of China, Chengdu, China

J. Wu (✉)
Department of Computer and Information Sciences, Temple University, Philadelphia, USA
e-mail: jiewu@temple.edu

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are becoming smarter and more heavily equipped with sensors and actuators use road infrastructure. These already existing vehicle functions can be achieved by enabling vehicles to collect more general sensor data for further enhancement for data transfer, such as the heterogeneous mobile sensor network.

The combination of fixed and mobile sensors and networking technologies into agile, error-prone, modern, and powerful networks can prove valuable to the data infrastructure of the smart city. However, this network faces its unique challenges in which some nodes are stationary and some are mobile, and there is a basic requirement to determine the optimal routing path for data transmission. We wanted to achieve a constant presence of sensors in the cities and they did not have a fixed network infrastructure re-input interconnection. To achieve this goal, we should use a heterogeneous approach that will utilize all possible network access points to achieve dynamic interconnection of all possible intelligent devices and sensors.

Vehicle Ad Hoc Networks (VANETs) are in the process of acquiring a related businesses because of recent advances in inter-vehicle communication through the DSRC/WAVE standard [2] and stimulating brand new visionary service vehicles from entertainment applications to travel/advertising information, from driver safety to opportunistic intermittent connectivity and Internet access [3, 4]. In particular, Vehicular Sensor Networks (VSNs) are becoming a new tool to effectively monitor the physical world, especially in urban areas where high concentrations of vehicles equipped with onboard sensors are expected [5, 6], as shown in Fig. 1. In addition,

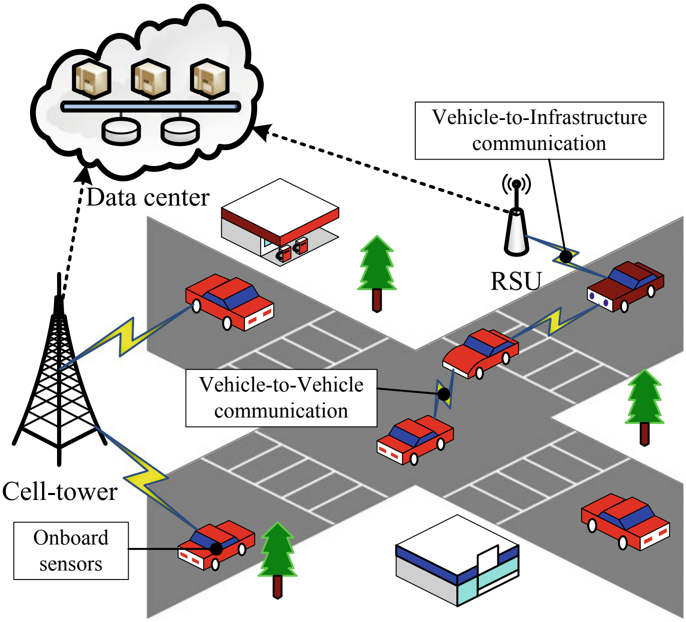


Fig. 1 The architecture of Vehicular Sensor Network (VSN)

with the onboard sensor and a 3G/4G mobile Internet connection, the growing popularity of smartphones sheds light on the use of smartphones as a platform involved in vehicle remote sensing [7]. As a result, the remote sensing platform for such vehicles will enable new applications such as street-level traffic estimation, ride quality monitoring, and active city surveillance.

Vehicles are usually not subject to stringent energy constraints and can easily be equipped with powerful processing units, wireless transmitters, and sensing devices even with some complexity, cost, and weight (GPS, cameras, vibration sensors, acoustic detectors, etc.). VSNs represent significant novelty and challenging deployment scenarios, and are significantly different from the more traditional wireless sensor network environments, and therefore, require innovative solutions. In fact, in a different way from conventional wireless sensor nodes, vehicles usually exhibit constrained movement patterns due to street layout, connections, and speed limitations. In addition, they usually have no strict limits on the processing power and storage capacity.

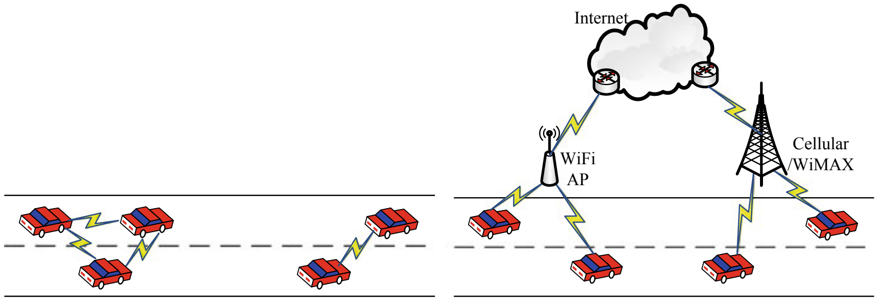
2 Background

2.1 Architecture

The Vehicle Sensor Network (VSN) platform provides a means for data collection/processing/access to the sensor. Vehicle sensor data is collected successively from city streets (for example, images, accelerometer data, and so on), and then processed to search for information of interest (for example, identification plate or to infer traffic patterns). Vehicle sensor information access network architecture depends largely on the wireless access method at the bottom of the vehicle environment. In general, the Vehicular Sensor Network (VSN) consists of three layers: a sensor layer, a communication layer, and a data process layer [8].

In the sensor layer, the vehicle is regarded as a large mobile sensor node. The vehicle is equipped with an Onboard Unit (OBU), which is an electronic device that can sense, communicate, and compute. It uses the OBU to sense the state of vehicle, such as the speed, moving direction, and location. OBU also senses the environment around the vehicle, such as the road traffic and climate. Moreover, most vehicles are equipped with a Global Navigation Satellite System (GNSS) device, which can offer positions and time synchronization for the vehicle, such as an American GPS or the Chinese BeiDou navigation satellite system (BDS).

The communication layer includes VANET, cellular network (3G or 4G), and mixed networks of the Internet. VANET uses the vehicles as mobile nodes in the MANET to create mobile networks. Every participating vehicle turns into a wireless router or node, allowing vehicles approximately 100–300 m around each other to connect and, in turn, create a network with a wide range. When the vehicle falls



(a) Vehicle-to-Vehicle (V2V) (b) Vehicle-to-Infrastructure (V2I)

Fig. 2 Communications in Vehicular Sensor Networks

in the signal range and when you exit the network, it can join other vehicles; the vehicles are then connected to each other, creating a mobile Internet.

If the vehicle is only equipped with vehicle communication equipment, it should operate in an infrastructure mode for free. Sensor data must be handled locally or in collaboration with vehicle-to-vehicle (V2V) communications [9, 10] to facilitate access to information, as shown in Fig. 2a. Roadside Units (RSU) are the fixed infrastructures which can help in forwarding the data packet to promote reliable communications. If the vehicle is also equipped with access methods, such as 3G/4G and WiMAX broadband wireless access, it can use a vehicle-to-infrastructure (V2I) communication sensor data sharing over the Internet. Mobile users can report the sensor's data to the Internet servers, and other users can access information from these servers [6], as shown in Fig. 2b.

The data processing layer includes two parts,namely, the data storage part and the data analysis part [8]. A lot of the vehicles' information, traffic data, and other data require the appropriate storage mechanism. Google's product is a stable solution, and is divided into three levels from the bottom up—basic file system (Google file system or the Colossus), database management (BigTable), and the programming model (MapReduce). Data analysis is important for the applications of VSN, which provides functions such as location-based services and vehicle monitoring services.

2.2 Environment

The impact of the environment on VANET is significant. The strategy of vehicular network under different environment will be different. The road structure under urban environment is regular, such as the grid road structure in Manhattan. The population density in urban environment is very high. Moreover, the vehicles in urban environment are driven at low speed due to the speed limit. Therefore, the data transmissions of the vehicular network under the urban environment are often in the inter-road mode, that is, the data packets are delivered along the multiple roads. On the contrary, the roads under rural environment are not structured, including several intercity roads and highways. Moreover, the traffic volume is relatively low. Because of the sparseness of roads and vehicles, the data transmissions of the vehicular network under the rural environment are often in the intra-road mode, where data packets are usually delivered among vehicles in the road, such as highway.

2.3 DSRC/WAVE Protocol Stacks

Dedicated short-range communication (DSRC) is working in a 5.9 GHz medium-distance communication technology of a short distance [2, 11]. Standards Committee E17.51 recognized a variant of the IEEE 802.11A MAC DSRC link. DSRC supports vehicles at speeds of up to 120 mph and a nominal range of 300 m (up to 1000 m), the default is a 6 Mbps data rate (up to 27 Mbps). This will be referred to as DSRC/WAVE (Wireless Access in a Vehicular Environment) in a variety of application environments to achieve and improve traffic flow, highway safety, and other Intelligent Transportation Systems' (ITS) application-related operations. DSRC has two modes of operation: (1) Ad hoc mode, which is characterized by distributed multi-hop networking (vehicle–vehicle), and (2) Infrastructure mode,which is characterized by a centralized mobile single-hop network (vehicle-gateway). Note that, depending on your deployment scenario, the gateways can be connected to each other or connected to the Internet, and they can be equipped with computing and storage devices, such as the Infostations [12].

3 Unique Challenges of Vehicular Networks

In vehicular ad hoc/sensor networks, the vehicles with radio ranges are regarded as the mobile nodes and routers to other nodes. The vehicular networks are similar to the traditional ad hoc networks, such as self-management, short radio transmission range, self-organization, and low bandwidth. However, the vehicular networks have unique challenges that affect the design of the routing protocols [13]. These challenges include the following:

High-speed mobility: The nodes in the traditional ad hoc networks (such as wireless sensor networks) are often stationary, and of course there are some sensor nodes that are moving, but the speed is slow,with the speed range of 1–5 m/s. In the vehicle sensor network, the node is in the city or highway moving vehicles, the speed range is usually 10–30 m/s, or even higher, so the node has high-speed mobility. Most existing researches in sensor networks assume that the entire network is connected after the deployment of sensor nodes, and any network node can be found in the network topology to a data sink node path. However, in the vehicle sensor network environment, this assumption is not established.

Intermittent connectivity: Intermittent connectivity in the network refers to the internode communication in the network that cannot guarantee a stable and continuous connection for a period of time, the connection is always intermittent. In [14], it is discussed that if the coverage radius of the node is 250 m at an average speed of 100 km/h, the probability of the link being 15 s is only 57%. The high-speed mobility of nodes can also cause rapid changes in network topology. In the car network, due to the high-speed mobility of nodes, the topology changes frequently. Network connectivity has a large impact on communication protocols, but the in-vehicle network is an intermittent connectivity network, making it difficult to establish end-to-end reliable connections.

Frequent changes in the topology: In the traditional ad hoc networks (such as wireless sensor networks) research, the vast majority is based on the traditional self-organizing network characteristics, assuming that the nodes are connected in the network, that is, each node in the network topology can find an end-to-end routing path to another node for data transmission. However, it is difficult to find such stable end-to-end routing path in a vehicular network. In the vehicular network, it is difficult to solve the problem of routing in the network by establishing a relatively stable routing table like the traditional network to manage the topology between nodes.

Opportunistic data delivery: In VANETs, the connectivity between nodes change frequently with the mobility of nodes, and the event of forwarding data occurs when a node meets with other nodes (in the range of communication radius of each other). Thus, the data transmission adopts the way of store and forward, that is, when the two nodes meet, they establish a wireless connection for exchanging information and storing data, and then forward this data to the next node encountered until the transfer to destination. However, the vehicle in the network does not understand the future travel route of its neighbors, so the uncertainty of such vehicle movements will lead to the way in which the mobile node-based data is forwarded. One solution is to copy the data and forward it to more vehicles in a multipath way to the target point, although the more data to be replicated to the neighbor vehicle will improve the efficiency of data transfer, but the vehicle sensor network resources are limited. This resource includes the network bandwidth and the network of mobile nodes in the cache space, if each car has copied a lot of data, then the network of these limited resources will soon be exhausted, but will affect the performance of data transmission.

In addition, we take the traffic hole problem as an example to illustrate the unique challenges VANETs [15]. The problem of traffic holes can be seen everywhere in the traffic environment. Even during peak hours, the traffic volume is the highest. The road shown in Fig. 3 is the Chengdu Bust Road, which is the busiest in Chengdu, and is the city with more than 2 million cars in China. The photos were taken in the afternoon peak hours. Initially, the traffic flow on this road was saturated, as shown in Fig. 3a. However, after 2 min, as shown in Fig. 3b, the traffic flow dropped sharply. After 3 min, as shown in Fig. 3c, there is no vehicle on this road and there is a gap. All vehicles on the road were blocked by traffic lights at the entrance. If the length of this gap is greater than the communication range (R) of the vehicle, the gap will block wireless communication between the vehicles.

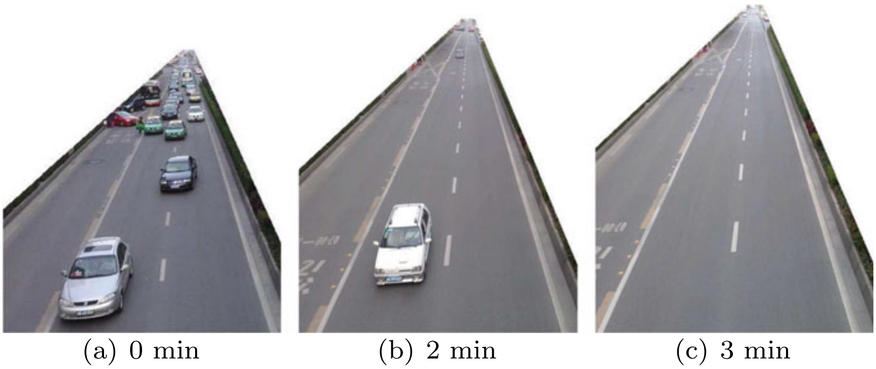


Fig. 3 Appearance of a traffic hole

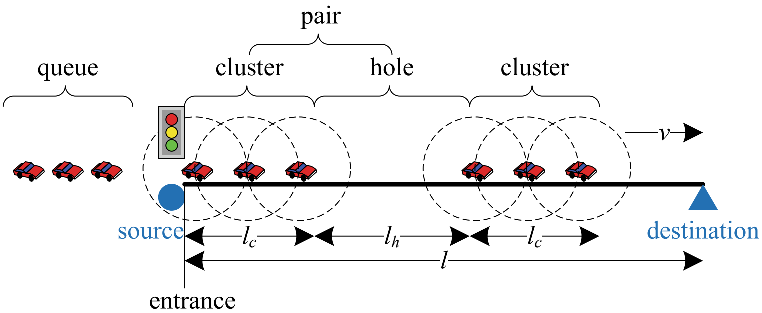


Fig. 4 The traffic hole and connected cluster on a road

The traffic flow which is regulated by the interaction among the vehicles and the roadways is called *uninterrupted flow*, such as a vehicle traveling on an interstate highway. In contrast, traffic flow which is caused by external means such as traffic lights or pedestrian signals is the term used as an *interrupted flow*. Figure 4 shows an example of the disrupted traffic flow along a road. The source of the sent data packet is at the road entrance, which is also a signal intersection. The destination is at the exit of the road or road. The distance between the source and the destination is l.

Let *traffic hole* be the gap in a traffic flow on the road. As shown in Fig. 4, its length (denoted by l_h) is larger than the communication range of the vehicles, i.e,. $l_h > R$. Let the *connected cluster* be a group of vehicles on the road that can communicate with each other via either one-hop or multi-hops communication, and its length is denoted by l_c, as shown in Fig. 4.

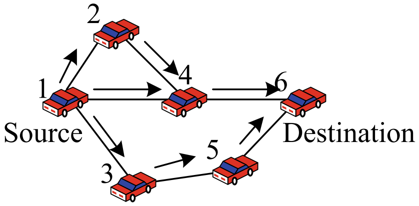
4 Routing in VANETs

In view of the different architectures, applications, and challenges, researchers have made a wide range of routing protocols for VANETs [13]. These protocols are mainly aimed at maximizing throughput while minimizing packet loss and control costs. One of the main challenges in VANET is the development of an efficient routing protocol for a highly variable topology. VANET needs new types of routing protocols. Opposite of the wired infrastructure, it does not use a dedicated router node. The routing protocols are used by the user node (vehicle), which can be mobile and unreliable. The current routing protocol for VANET can be divided into two main categories: vehicle-to-vehicle-based (V2V) routing protocols and vehicle-to-infrastructure-based (V2I) routing protocols. V2V protocols perform vehicle-to-vehicle communication but do not focus on fixed infrastructures on roads. It can be divided into four groups: (1) topology-based (ad hoc) routing protocols, (2) position-based routing protocols, (3) cluster-based routing protocols, and (4) broadcast-based (geocast) routing protocols. Moreover, the deployment of a communications infrastructure and the road to vehicle communication is more reliable and reduces unwanted delays in the application of different vehicles.

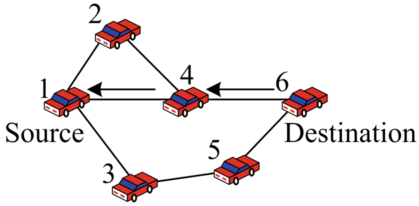
4.1 Topology-Based (Ad Hoc) Routing Protocols

Topology-based routing uses existing communication links to forward packets. Ad hoc On-demand Distance Vector (AODV) [16] is a refinement of the DSDV Protocol. AODV differs from DSDV because it reduces the number of broadcast messages and the routing is created on-demand. However, DSDV maintains all the routes listed in the routing table.

The source node in AODV uses a Hello Beacon to detect its neighbor to start the routing protocol. As shown in Fig. 5a, to find the path to the destination, the source node broadcasts a Route Request Packet (RREQ), and then its neighbor broadcasts the RREQ to its neighbors until it reaches the route to the destination node. After



(a) Propagation of RREQ



(b) RREP's path to the source

Fig. 5 AODV routing protocol

receiving the RREQ packet, the node will register the address of the node sending the query in its routing table. The method of registering the previous hop is called learning later. As shown in Fig. 5b, after reaching the target node, the Route Reply Packet (RREP) is transmitted through the path from the back to the source.

When the source node moves, the route to the destination is established. If one of the intermediate nodes moves, then its neighbor realizes the link failure and sends a notification of the link failure to its upstream neighbors, and so on until it reaches the source. Thus, if needed, the source can reinitiate the process of route discovery again. Due to the periodic beaconing, the protocol tends to run out of the extra bandwidth. In addition, a single RREQ with multiple RREP packets will cause a serious control overhead.

4.2 Position-Based Routing Protocols

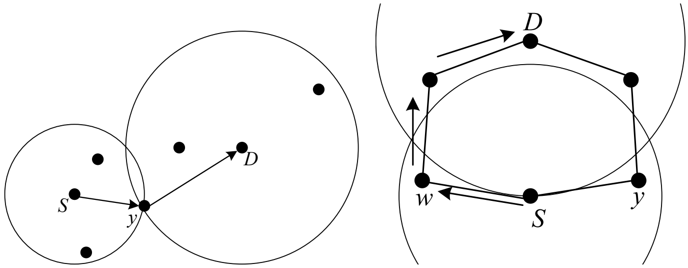
In the position-based routing protocol, all nodes point devices, such as GPS location, to identify their own position and their neighbors geographically [16]. It does not manage any routing table or exchange associated with the neighbor link state information. Information from the GPS equipment is used to make routing decisions. This type of routing performs better, because creating and maintaining global routing from the source node to the destination node is not necessary. Location-based routing protocols can be classified as non-delay-tolerant network (non-DTN) routing protocols, and delay-tolerant network (DTN) routing protocols.

4.2.1 Non-delay-Tolerant Networks (non-DTNs) Routing Protocols

Non-DTN routing protocols do not use the alternating connectivity, and are valid only in sufficiently populated vehicular networks. These protocols are designed to deliver data packets to the destination as soon as possible. The basic idea of the greedy method of non-DTN routing protocols is that a node sends its data packet to one of its neighbors that is closer to the destination. However, if the neighbors are not closer to the destination than that node, the forwarding policies may not be successful. Therefore, we can claim that the routing protocol has reached the local maximum at the node, because it has achieved the maximum local growth at the current node. The routing protocols in that group have their own recovery method to handle such a failure.

Greedy Perimeter Stateless Routing (GPSR) [17] is a location-based routing protocol aimed at addressing the mobile environment. GPSR is most suitable on the highway in which nodes are uniformly distributed. This routing protocol depends on the following two modes:

Greedy mode where the node forwards a data packet to one of its neighbors that is closer to the destination node by considering the position of the neighbors in the network topology. As shown in Fig. 6a, the node S wants to send a data packet



(a) Greedy forwarding mode (b) Perimeter forwarding mode

Fig. 6 GPSR routing protocol

destined for node D. S, sends the data packet to the node y, which is in S's neighbors and is closer to D than any of S's other neighbors.

Perimeter mode is used as the protocol recovery mode when the packet reaches a local maximum. Therefore, the recovery mode is used to forward packets to nodes that are closer to local destinations than where the packets are facing local maximums. A simple example of this topology is shown in Fig. 6b. The node S is closer to the destination node D than its neighbors w and y. S does not choose to forward data packets to w or y using greedy forwarding, although the two paths to D are $S - y - z - D$ and $S - w - v - D$. In this case, the GPSR protocol declares S as the local maximum to D, and the shaded area has no nodes, as in the invalid area. To route packets around invalid areas, the perimeter of the forwarding strategy constructs a planarized graph for the neighbor node S and routes the invalid packets around the packet with the right-hand rule. The right-hand rule states that when the node reaches from y to S, the traversed edge is a counterclockwise rotation around S from edge (x, y). By applying the right-hand rule shown in Fig. 6b, the data from node S forwards the packet to the hop w.

4.2.2 Routing Protocols for Delay-Tolerant Networks (DTNs)

DTN is a method of solving computer network architecture problems in a heterogeneous network that may lack continuous network connectivity, and consequently, lacks instantaneous end-to-end paths. Examples of such networks are those that operate in mobile or extreme terrestrial environments or planned cyberspace. The development of the routing protocol of the vehicle has been regarded as a kind of DTN characteristic. Given the challenging environment of such networks, they are subject to a periodic connection loss. In order to solve this problem, the packet transmission is increased by allowing nodes to store data packets when they lose contact with other nodes, and put the data packets at a certain distance as long as it satisfies the other nodes according to some indicators with the neighboring nodes; this is called the carry-and-forward strategy.

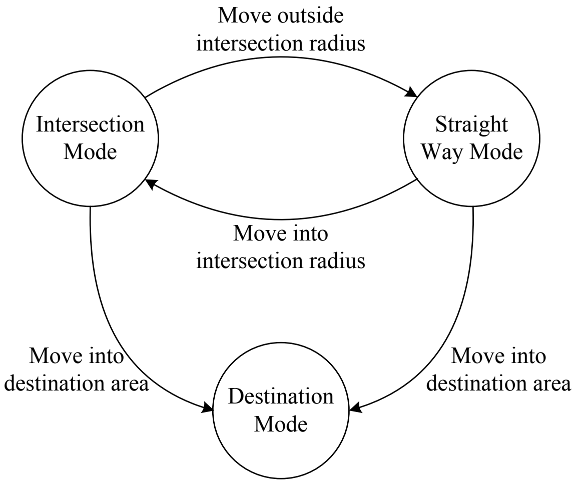


Fig. 7 The transition modes in VADD

Vehicle-assisted data delivery (VADD) [18] is a routing strategy for vehicles that is intended to enhance the routing of vehicles based on the concept of carry-and-forward by utilizing the mobility of vehicle. A car makes a decision at an intersection while selecting the next forwarding path with a negligible delivery delay. The path is an intersection where only the split path is split. The best path for packet forwarding is switched between the three packet modes (Intersection, Straight Way, and Destination). As shown in Fig. 7, VADD has three packet patterns: Intersection, Straight Way, and Destination based on the location of the packet carrier (i.e., the vehicle which carries the data packet). By switching between these packet modes, the packet carrier needs the best packet forwarding path. Between the three modes, the Intersection mode is the most critical and complex one, because the vehicle at the intersection has the most choices.

4.3 Cluster-Based Routing Protocols

In general, cluster-based routing protocols are more suitable for network cluster topology. Each cluster has a cluster head for intercluster management purposes. The intra-cluster nodes interact with each other through direct contact, while cluster-to-cluster interactions are performed through the cluster headers. In a cluster-based routing protocol, the clusters are formed close to each other. However, in cluster-based routing protocols, cluster configuration and cluster head selection is an important issue. Due to the high mobility of VANET, dynamic cluster configuration becomes a major process.

In the Cluster-Based Directional Routing Protocol (CBDRP) [19], vehicles traveling on the same route are split into several clusters. Each vehicle can communicate

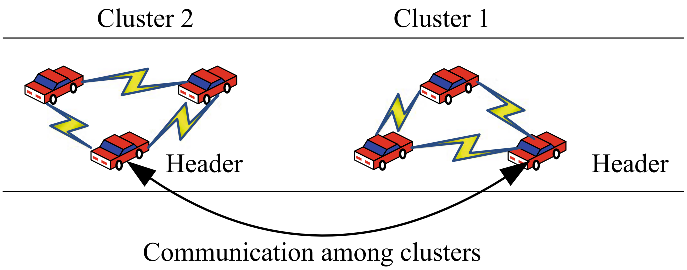


Fig. 8 Cluster splitting example in CBDRP

with its neighbors in the same cluster by radio. An example of cluster splitting is shown in the Fig. 8. The figure shows two clusters. The center of a cluster is fixed after it partitions. The CBDRP protocol assumes that the radius of the radio is r, the length of each cluster is d, and the half-width of the road is w. Given that $d > w$, d is almost equal to $r/2$. The radio transmission radius of 802.11 p is 1000 m, so the theoretical length of a cluster can be as high as 500 m. D can be much larger if the header is near the center. The source node in CBDRP forwards the message to its cluster head, and then sends the message to the header, which is located in the same cluster as the destination. Eventually, the destination header forwards the message to the destination. Select the cluster header; the persistence is similar to CBR, but it considers the speed and direction of the vehicle. Simulation results show that CBDRP can solve the link stability of the vehicle, so as to ensure reliable and fast data transmissions.

4.4 Broadcast-Based Routing Protocols

Broadcast-based routing is commonly used by VANET to share information about traffic, weather, and emergencies, car usage, and advertising and announcements for the [20]. Broadcast-based routing protocols follow simple broadcast flooding in which each node resends to other nodes. This process guarantees the arrival of all destination messages, but with a high overhead. In addition, it is only suitable for a large number of smaller nodes in the network. A larger node density results in more message broadcasts resulting in collisions, higher bandwidth utilization, and overall system performance degradation.

Urban multi-hop broadcast (UMB) [21] aims to address (i) broadcast storms, (ii) hidden nodes and (iii) reliability problems in multi-hop broadcasts in urban areas. This protocol assigns forwarding and acknowledgment to only one vehicle. It splits the sections of the road inside the transmission range into portions, and selects the vehicle in the furthest non-empty segment without a priori of topological information. When there is an intersection in the path of the message propagation, a new directed broadcast is initiated by the repeater at the intersection.

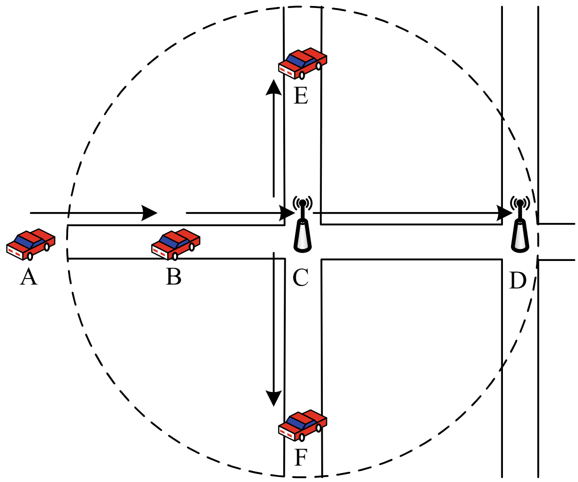


Fig. 9 Intersection handling in UMB protocol

Figure 9 illustrates an example of intersection handling in UMB, where the directed broadcast is used in the case where the vehicle A reaches the vehicle B. Vehicle A is out of the transmission range of repeater C. At the same time, the vehicle B is in the transmission range of the repeater C. Therefore, the vehicle B uses the IEEE 802.11 protocol for the communication repeater C. Once the repeater receives the message, it initiates a directed broadcast of the north and south directions. Since the repeater D is in the transmission range of C, C also sends the packet to the repeater D by using the IEEE 802.11 protocol.

In addition, data delivery in VANETs can be divided into two categories, road delivery and delivery delivery. Since traffic is two-way, data delivery on roads is much simpler than delivery. Therefore, the opportunistic forwarding through intermittent connections between intersections and vehicle nodes is a challenging issue in VANETs. In order to overcome this problem, a Buffer and Switch protocol (BAS) [22] was proposed. The basic idea behind this is to use the vehicle nodes on each road to buffer multiple propagated packets in order to provide more opportunities for packet switching at the intersection. Due to resource limitations in VANETs (such as vehicle node bandwidth and storage space), BAS employs space–time controlled repeat propagation on the routing path. Unlike conventional protocols in VANETs, duplicates in the BAS propagate not only to the preceding vehicle node (called *downstream propagation*) but also to the nodes along the routing path (called *upstream propagation*). For the effective packet switching at each intersection, each packet on the previous road must be: (1) Using greedy forwarding protocol to timely forward to the intersection; (2) Spread to more vehicle nodes to provide more opportunities for effective packet switching at the crossroads. We call it the way to buffer packets.

Therefore, the propagation on the road consists of two phases: (1) Downstream propagation: In order to send packets in time to the expected next intersection, each packet transmitted on the node is copied to its neighboring location and is closest to the destination along the routing path, and any of its neighbors hold this package in front of it; (2) Upstream Propagation: For buffering packets on the road, each packet carried in the node is also copied to its next adjacent location, which is the furthest location along the routing path and behind it. In addition, in order to reduce resource consumption, this spread is limited on this road.

4.5 Infrastructure-Based Routing Protocols

The placement of a fixed RSU, linked to the exact location of the backbone, is a necessary condition for communication. The number and distribution of RSUs depends on which communication protocols have to be adopted. For example, some protocols require that RSUs be evenly distributed throughout the entire road network, while some others only need to be at intersections, and others only need to be at the regional boundaries. It can be assumed that the infrastructure is beaten to a certain level and the vehicle occasionally has access to it.

RSUs in VANET offer two potential benefits: In the first case, the higher antenna height increases the reliability of the Vehicle-to-Infrastructure (V2I) communications compared to Vehicle-to-Vehicle (V2V) communications. In addition, the deployment of RSUs are connected to a higher bandwidth and a more reliable backbone network, providing traffic management departments with centralized access, enabling configuration, and maintenance of these units.

The routing protocol of Static node-assisted adaptive (SADV) [23] is designed to minimize the message delivery delay in sparse networks, and adjusts to varying traffic densities by enabling each node to estimate the amount of the message delivery delay. SADV assumes each single vehicle and knows its location via GPS, and each has access to an external static street map. There are three different modules for SADV: (1) Static Node-Assisted Routing (SNAR), (2) Link Delay Update (LDU), and (3) Multipath Data Dissemination (MPDD).

SADV operates a road mode and an intersection mode. SNAR determines the optimal path by using the graph based on the abstract from the roadmap. The LDU maintains a delay matrix that dynamically measures the delay between the message-passing static nodes. MPDD assists in multipath routing. Static nodes in the SADV have a similar concept, such as Throwbox, which can store and forward data in the DTN routing protocol, where the SADV can store and forward the data necessary for the device. However, SADV is different from regressive because SADV does not require the node contact option, but requires the implementation of static nodes and routing algorithms to take advantage of the street map structure and vehicle density for each road in the vehicle network.

The static node may store the packet for a period of time until the shortest delay path becomes available. As shown in Fig. 10, the packet is sent from A to the remote location. Once the packet is transferred from A to B, the latter has determined that the packet is to be forwarded to the next vehicle. For example, it is assumed that the shortest delay path to the packet is to the north, but no traffic within the

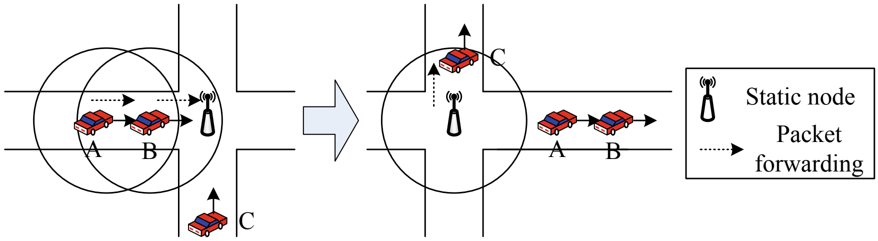


Fig. 10 SNAR mode in SADV routing protocol

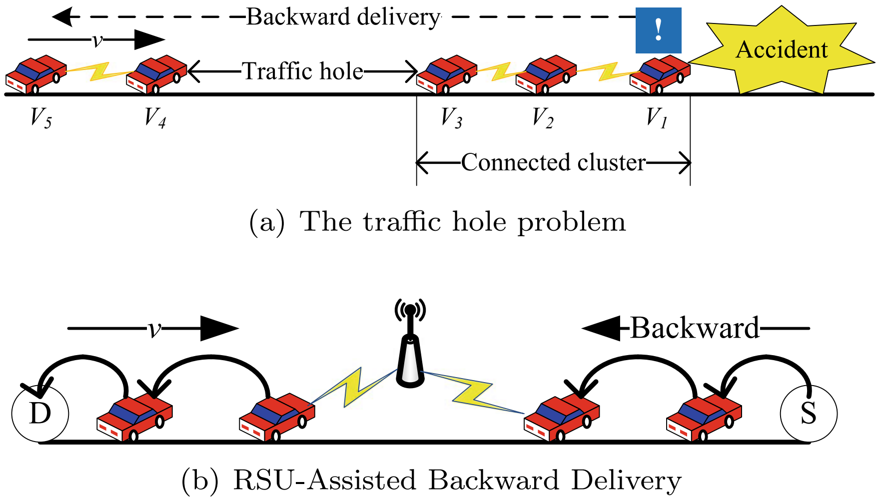


Fig. 11 Backward data delivery in VANETs

communication range of the vehicle *B* can transmit the packets along this direction. Therefore, *B* transmits the data packets to the static node. The static node stores the packet for a period of time and sends it to *C* as it crosses the intersection to north of the road, as shown to the right of Fig. 10. Without support from the static node, the packet will be moved via *B* to the east of the road. However, if it does not meet *C* at the intersection, it may take a fairly long time for the packet to travel.

Another example is the backward data delivery in VANETs. Many applications in VANETs require delivering data packets backwards. In sensing applications, vehicles need to obtain the conditions about the roads that lie ahead of them. As an example in Fig. 11a, an alert message needs to be delivered from the first vehicle, V1, to the 5th vehicle, V5. The total data delivery delay is calculated from the interval time between when the first vehicle generates the alert message and when V5 receives the message.

Data delivery with V2V communications in VANETs is based on the vehicles on the roads, but the distribution of the vehicles could be affected by their mobilities or by external means, such as traffic lights. A gap with a distance larger than the communication range of the vehicles could appear along the traffic flow; this is considered a traffic hole. It could block the data delivery along the traffic flow. As shown in Fig. 11a, when the distance between the vehicles V3 and V4 is larger than their communication range R, a traffic hole appears in the road traffic flow and partitions the road traffic flow into two connected clusters. On a one-way road, the message is backwardly delivered from the vehicle V3 to V4, and is blocked by the traffic hole. Because the data are headed in the direction opposite to that of the motion of the vehicle, no available vehicles can carry the data to the destination using the movement-assisted routing protocol.

We can utilize some static roadside units (RSUs) to help forwarding the packets to reduce the data delivery delay, as shown in Fig. 11b. An RSU can be a wireless access point, a parked vehicle, vehicles waiting at an intersection, or the static node. The RSU only acts as a relay, so it incurs a lower cost than a traditional access point. We term this type of data delivery as RSU-Assisted Backward Delivery (RABD) [24]. Each road can be regarded as a river. The vehicles are regarded as boats, and they can move from upstream to downstream. Thus, each RSU can be seen as a dock for delivering the data packets.

5 Macro–Micro Model for Routing Protocols

Without considering the details of highly dynamic network topology, we propose a model called Macro–Micro model based on our understanding of the VANET characteristics to analyze and resolve the routing problems in VANETs. Macro–Micro model divides the vehicular network into macroscopic level (Macro) and microscopic level (Micro). The Macro provides information for computing routing strategies in VANETs, and the Micro defines the data delivery protocols which guarantee packets are effectively delivered to their destinations.

5.1 State Awareness Routing Protocols

Depending on state awareness, routing protocols in VANETs can be classified into three categories, namely, state-aware, stateless, and hybrid routing protocols. State-aware protocols, such as DSR [25] or AODV [16], maintain a routing state (routing table or routing path) in the communicating nodes. The state-aware protocols are not adapted to VANETs due to the short duration of the routing states and the overhead of their maintenance. Due to high mobility, the topology of VANETs changes rapidly. Such particular features often make these protocols inefficient or unusable in VANETs. Therefore, a direct approach is to develop stateless routing protocols, i.e., protocols that do not maintain routing states, such as greedy routing GPSR [17]. However, the researchers in [18, 26, 27] have argued that the greedy routing lacks knowledge of topology and may fall into a local minimum. Although a recovery mode can be used to escape from the local minimum, it is not efficient if packets spend more time in the recovery phase than in the greedy phase. Hybrid protocols use a combination of state-aware and stateless approaches. Since vehicles should try to make use of the wireless communication channel as much as possible, packets will be transmitted along the path with higher road traffic density. Previous researches [18, 27] use density and road lengths as the metric for route creation which is state-aware, and deliver packets by some greedy protocols which are stateless.

However, they haven't considered the network congestion which could seriously affect the packet delivery delay of each road. Because all vehicles use traffic density as metric for route creation, most packets will be delivered along those roads with higher density. With the increase in the number of packets, because of limited resources (buffer and bandwidth), network congestion may arise in these roads, and thus decreasing the protocols performance in terms of delivering packets. However, traffic densities of these roads can not be affected by the network congestion, so vehicles will continue to deliver packets to them. This can reduce the performance of packets delivery in the network.

5.2 Macro–Micro Model

In [28], the authors propose that due to the lack of knowledge of network topology evolution, the design of effective routing strategies for opportunistic networks is usually a complex task. When more knowledge about the expected topology of the network is available, routing performance will increase [28, 29]. Unfortunately, this knowledge is not readily available, and tradeoffs must be made between performance and knowledge needs. Therefore, in Macro–Micro model, we have studied the collection of more valuable routing information in macros. This macro has state awareness, which relates to the services provided by the road, such as packet delivery delay or travel time, and is typically used to calculate packet routing strategies or vehicle travel plans. The routing policy may be the same as a single routing path (such as GPSR [17]) or multiple routing paths (such as epidemic routing [30]).

In Micro level, we investigate the details of data packets delivery in the vehicular network with two necessary units, which are the vehicle node (or Roadside Unit, RSU) and the data packet. The Micro level analyzes and manages the interactions between the vehicle nodes and the data packets. The moving vehicles in VANETs are equipped with wireless onboard units (OBUs), which communicate with each other or RSUs by a dedicated short range communications (DSRC) [4] protocol. For analyzing the vehicle nodes, we consider two properties of vehicles, which are mobility and communication. The movement of vehicles is directional, and the mobility property of a vehicle node includes speed, acceleration, direction, GPS position and so on. Some studies [18, 26] have presented that vehicle nodes in a vehicular network can periodically broadcast HELLO beacon message about their mobility properties to

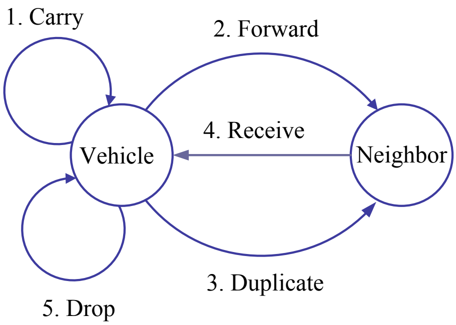


Fig. 12 State diagram of data packet

their neighbors, and each node can obtain the mobility information of its neighbors by the beacon messages.

The communication property of a vehicle node includes the protocols in the physical layer, the data link layer, the network layer and so on. A vehicle node can communicate with other nodes by some wireless communication devices, and the vehicle nodes interact with packets through this property. In Fig. 12, we present the possible states of data packets and the associated transition diagram, and we classify the interactions between the vehicle nodes and the data packets into five categories: (1) Carry: the vehicle node stores the packet in its local buffer and moves; (2) Forward: the vehicle node forwards the packet to another node through wireless communication; (3) Duplicate: the node duplicates the packet and forwards a copy of it to another node; (4) Receive: the node receives the packet from one of its neighbors; (5) Drop: the node deletes the data packet from its buffer. Based on these categories, various protocols can be used for data delivery in Micro, such as greedy forwarding [17], epidemic routing [30] and so on.

5.3 Mapping in Macro–Micro Model

We can map the categories of state awareness routing protocols to Macro–Micro model, and analyze them based on it. As shown in Fig. 13, the x-axis denotes the awareness of states, and the y-axis denotes the levels in VANETs which are the Macro and the Micro. State-aware protocols (such as AODV and DSR), which are regardless of state in Macro and are state-aware in Micro, are mapped to the quadrant II and IV. Stateless protocols (such as GPSR), which are regardless of state both in Macro and Micro, are mapped to the quadrant II and III. Hybrid protocols (such as VADD and LOUVRE), which are state-aware in Macro and stateless in Micro, are mapped to the quadrant I and III. These protocols are summarized in Table 1.

As we have discussed, the state-aware and stateless protocols cannot effectively solve routing problems in VANETs. However, some hybrid protocols [18, 27] deliver packets with greedy forwarding protocols which are based on some stable statistics

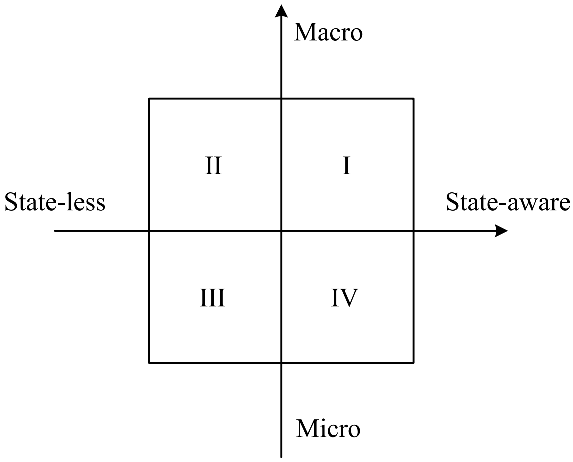


Fig. 13 Mapping in Macro–Micro model

Table 1 Overview of the routing protocols in Macro–Micro model

Level	Micro		Macro	
State	State-aware	Stateless	State-aware	Stateless
DSR [25]	√			√
AODV [16]	√			√
GPSR [17]		√		√
Epidemic [30]		√		√
VADD [18]		√	√	
LOUVRE [27]		√	√	
BAS [22]		√	√	

such as traffic density. We will utilize Macro–Micro model to analyze the effectiveness of these protocols.

VADD in [18] utilizes the estimation of packet forwarding delay through each road, which is based on some statistical data such as the average vehicle density, for route creation. Then, it proposes a greedy protocol to deliver packets. From Macro–Micro models perspective, VADD also includes two levels: the Macro is the estimation of packet forwarding delay of each road, and the Micro is the greedy forwarding protocol. As we have introduced, the purpose of Macro is to provide effective information for route creation. However, VADD is based on preloaded statistics which cannot adapt to the changing conditions in VANETs. Moreover, because it utilizes average vehicle density to estimate packet forwarding delay of each road, this may result in inaccurate estimation and cause the network congestion. As a result, the performance of VADD may be reduced.

Like VADD, LOUVRE [27] also uses density and road lengths as the metric for route creation in Macro. And the authors assume that vehicles are uniformly

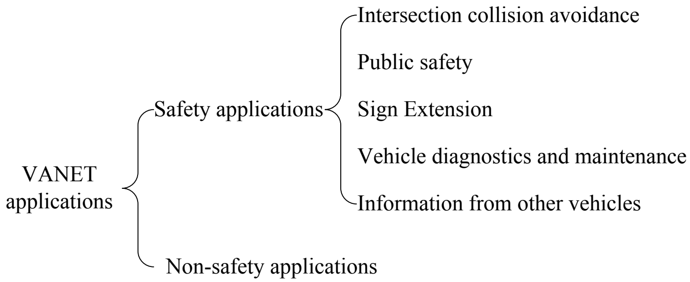


Fig. 14 Categories of VANET applications

distributed along a road. As long as the number of cars on the road is greater than or equal to a density threshold, the authors consider that the road is connected for routing. However, this assumption may not hold in a real VANET with highly dynamic topology and nonuniform node distribution.

6 Vehicular Sensing Applications

The communications of vehicle-to-vehicle and the vehicle-to-infrastructure in VANETs can support a large number of applications which require the data transmissions among the users or the devices [31–34]. Different types of sensors and GPS receivers are integrated with the network interface onboard devices that grant the vehicle the ability to collect, process, and disseminate information about itself and other vehicles approaching it in its environment. This has led to improved road safety and the provision of passenger comfort to [35, 36]. As shown in Fig. 14, the VANET applications are classified as safety applications and non-safety applications [37].

6.1 Safety Application

The safety applications use wireless communication between vehicles or between vehicles and infrastructures to improve road safety and avoid accidents; its intention is to save human lives and provide a clean environment. Safety applications are used for their ability to collect information from vehicle sensors, from other vehicles, or both, in order to process and disseminate information to other vehicles or infrastructures depending on the application and its function. The application of wireless communication technology in vehicles to communicate with other vehicles or infrastructures enables a wide range of applications and leads to increased road safety levels.

Safety applications that use V2V and/or V2I communications can be classified as [37]: (1) intersection collision avoidance, (2) public safety, (3) sign extension, (4) vehicle diagnostics and maintenance, and (5) information from other vehicles. For example, [38] propose the application of warning about violating traffic signals. This application is designed to send a warning message to the vehicle and warn the driver that a dangerous situation (accident) will occur if the vehicle does not stop; when the traffic light is running, signaling to stop sending messages depends on several factors such as traffic status, time, speed, vehicle location, and road surface. Improving the intersection collision avoidance system will lead to avoiding many road accidents, and the system is based on V2V or V2I communications.

6.2 Non-safety Application

The non-safety applications are designed to enhance the comfort of drivers and passengers (making the journey more enjoyable) and improve traffic efficiency [37]. They can provide drivers or passengers with weather and traffic information and detailed information on the location of the nearest restaurants, gas stations, or hotels, and their prices. Passengers can play online games, access the Internet, and send or receive instant messages, although the vehicle is connected to the infrastructure network.

The comfort of rides has been identified as one of the highest standards affecting customer satisfaction with public transport systems; thus, comfort is an important consideration for passengers using public transport. In particular, some passengers (such as pregnant women, children, and patients) need a more comfortable riding experience while traveling. The factors affecting passengers' ride comfort include: (1) individual factors such as driver behavior or vehicle condition; and (2) road conditions that affect most vehicles on a road.

Based on smartphones, a system [39] named Riding Experience Sensor (RESen) is proposed to sense and evaluate the riding experience. With the help of participatory phone sensing, RESen harvested a riding experience while driving and classified the experience horizontally and vertically. In order to adapt to a variety of different phone configurations, RESen can feel the horizontal and vertical experience and any direction. Based on the collection of participatory sensor data, RESen can evaluate the riding experience of three levels (track, road and driver). For trajectories, RESen should provide an overall riding experience, including anomalies along it. For a path, RESen will evaluate its riding experience, based on the track that passes it. RESen can evaluate the driver by comparing his trajectory and the riding experience of the road. Based on the evaluation, RESen can not only improve the driver's behavior, but also provide the user with a comfortable travel plan.

7 Conclusion and Future Research Directions

In this chapter, we studied the Vehicular Ad Hoc/Sensor Networks in Smart Cities. We presented the architecture and DSRC/WAVE Protocol stacks in vehicular sensor networks. We discussed the unique VANET challenges. We introduced the different kinds of routing protocols in VANETs. Moreover, we presented the vehicular sensing applications. In the future, we believe that new routing protocols can be provided for vehicular sensor networks, as well as other factors involved in our discussion for different kinds of applications in smart cities. In general, the field of vehicular network (VANET or VSN) is a new and growing area, which expects good perspective for the future.

References

1. Tomaš, B., Vrček, N.: Smart City Vehicular Mobile Sensor Network, pp. 70–77. Springer International Publishing, Cham (2015)
2. Lee, U., Gerla, M.: A survey of urban vehicular sensing platforms. Comput. Netw. Int. J. Comput. Telecommun. Netw. **54**(4), 527–544 (2010)
3. Nandan, A., Das, S., Pau, G., Gerla, M., Sanadidi, M.Y.: Co-operative downloading in vehicular ad-hoc wireless networks. In: Conference on Wireless On-Demand Network Systems and Services, pp. 32–41 (2005)
4. Xu, Q., Mak, T., Ko, J., Sengupta, R.: Vehicle-to-vehicle safety messaging in DSRC. In: Proceeding of International Workshop on Vehicular Ad Hoc Networks, pp. 19–28 (2004)
5. Lee, U., Lee, J., Park, J.S., Gerla, M.: FleaNet: a virtual market place on vehicular networks. IEEE Trans. Veh. Technol. **59**(1), 344–355 (2010)
6. Hull, B., Bychkovsky, V., Zhang, Y., Chen, K., Goraczko, M., Miu, A., Shih, E., Balakrishnan, H., Madden, S.: CarTel: a distributed mobile sensor computing system. In: Proceedings of ACM SenSys, pp. 125–138 (2006)
7. Mohan, P., Padmanabhan, V.N., Ramjee, R.: Nericell: rich monitoring of road and traffic conditions using mobile smartphones. In: International Conference on Embedded Networked Sensor Systems, pp. 323–336 (2008)
8. Liu, J., Wan, J., Wang, Q., Deng, P., Zhou, K., Qiao, Y.: A survey on position-based routing for vehicular ad hoc networks. Telecommun. Syst. **62**(1), 15–30 (2016)
9. Lee, U., Zhou, B., Gerla, M., Magistretti, E., Bellavista, P., Corradi, A.: Mobeyes: smart mobs for urban monitoring with a vehicular sensor network. IEEE Wirel. Commun. **13**(5), 52–57 (2006)
10. Lee, U., Magistretti, E., Gerla, M., Bellavista, P., Corradi, A.: Dissemination and harvesting of urban data using vehicular sensing platforms. IEEE Trans. Veh. Technol. **58**(2), 882–901 (2009)
11. Jiang, D., Taliwal, V., Meier, A., Holfelder, W., Herrtwich, R.: Design of 5.9 GHz DSRC-based vehicular safety communication. IEEE Wirel. Commun. **13**(5), 36–43 (2006)
12. Frenkiel, R.H., Badrinath, B.R., Borres, J., Yates, R.D.: The infostations challenge: balancing cost and ubiquity in delivering wireless data. IEEE Pers. Commun. **7**(2), 66–71 (2000)
13. Sharef, B.T., Alsaqour, R.A., Ismail, M.: Vehicular communication ad hoc routing protocols: a survey. J. Netw. Comput. Appl. **40**(1), 363–396 (2014)
14. Rudack, M., Meincke, M., Lott, M.: On the dynamics of ad hoc networks for inter vehicle communications (IVC). In: International Conference on Wireless Networks (2002)
15. Song, C., Wu, J., Liu, M.: On characterization of the traffic hole problem in vehicular ad-hoc networks. In: Proceedings of IEEE GlobeCom (2013)

16. Perkins, C.E., Royer, E.M.: Ad-hoc on-demand distance vector routing. In: Proceedings of Workshop on Mobile Computing Systems and Applications, pp. 90–100 (1999)
17. Karp, B., Kung, H.T.: GPSR: greedy perimeter stateless routing for wireless networks. In: International Conference on Mobile Computing and Networking, pp. 243–254 (2000)
18. Zhao, J., Cao, G.: VADD: vehicle-assisted data delivery in vehicular ad hoc networks. In: Proceedings of IEEE INFOCOM, pp. 1–12 (2008)
19. Song, T., Xia, W., Song, T., Shen, L.: A cluster-based directional routing protocol in VANET. In: IEEE International Conference on Communication Technology, pp. 1172–1175 (2010)
20. Zeadally, S., Hunt, R., Chen, Y.S., Irwin, A., Hassan, A.: Vehicular ad hoc networks (VANETs): status, results, and challenges. Telecommun. Syst. **50**(4), 217–241 (2012)
21. Korkmaz, G., Ekici, E., Ozguner, F., Ozguner, U.: Urban multi-hop broadcast protocol for inter-vehicle communication systems. In: ACM International Workshop on Vehicular Ad Hoc Networks, pp. 2062–2063 (2004)
22. Song, C., Liu, M., Wen, Y., Cao, J., Chen, G.: Buffer and switch: an efficient road-to-road routing scheme for VANETs. In: International Conference on Mobile Ad-Hoc and Sensor Networks, pp. 310–317 (2011)
23. Ding, Y., Wang, C., Xiao, L.: A static-node assisted adaptive routing protocol in vehicular networks. In: International Workshop on Vehicular Ad Hoc Networks, pp. 59–68 (2007)
24. Song, C., Wu, J., Yang, W.-S., Liu, M., Jawhar, I., Mohamed, N.: Exploiting opportunities in V2V transmissions with RSU-assisted backward delivery. In: INFOCOM 2017 6th IEEE International Workshop on Mission-Oriented Wireless Sensor and Cyber-Physical System Networking (MiSeNet'17) (2017)
25. Johnson, D.B., Maltz, D.A.: Dynamic source routing in ad hoc wireless networks. In: Mobile Computing, pp. 153–181 (1996)
26. Naumov, V., Gross, T.R.: Connectivity-aware routing (CAR) in vehicular ad-hoc networks. In: Proceeding of IEEE International Conference on Computer Communications, pp. 1919–1927 (2007)
27. Lee, K.C., Le, M., Harri, J., Gerla, M.: LOUVRE: landmark overlays for urban vehicular routing environments. In: Proceeding of IEEE Vehicular Technology Conference, pp. 1–5 (2008)
28. Pelusi, L., Passarella, A., Conti, M.: Opportunistic networking: data forwarding in disconnected mobile ad hoc networks. IEEE Commun. Mag. **44**(11), 134–141 (2006)
29. Jain, S., Fall, K., Patra, R.: Routing in a delay tolerant network. ACM SIGCOMM Comput. Commun. Rev. **34**(4), 145–158 (2004)
30. Vahdat, A., Becker, D.: Epidemic routing for partially-connected ad hoc networks, Master Thesis
31. Rashid, B., Rehmani, M.H.: Applications of wireless sensor networks for urban areas. J. Netw. Comput. Appl. **60**, 192–219 (2016)
32. Kafi, M.A., Challal, Y., Djenouri, D., Doudou, M., Bouabdallah, A., Badache, N.: A study of wireless sensor networks for urban traffic monitoring: applications and architectures. Procedia Comput. Sci. **19**(Complete), 617–626 (2013)
33. Piran, M.J., Murthy, G.R., Babu, G.P.: Vehicular ad hoc and sensor networks; principles and challenges. Int. J. Ad Hoc Sens. Ubiquitous Comput. **2**(2), 38–49 (2011)
34. Mednis, A., Elsts, A., Selavo, L.: Embedded solution for road condition monitoring using vehicular sensor networks. In: International Conference on Application of Information and Communication Technologies, pp. 1–5 (2012)
35. Jakubiak, J., Koucheryavy, Y.: State of the art and research challenges for VANETs. In: Consumer Communications and Networking Conference, pp. 912–916 (2008)
36. Wischhof, L., Ebner, A., Rohling, H.: Information dissemination in self-organizing intervehicle networks. IEEE Trans. Intell. Transp. Syst. **6**(1), 90–101 (2005)
37. Al-Sultan, S., Al-Doori, M.M., Al-Bayatti, A.H., Zedan, H.: A comprehensive survey on vehicular ad hoc network. J. Netw. Comput. Appl. **37**(1), 380–392 (2014)

38. Rawashdeh, Z.Y., Mahmud, S.M.: Intersection collision avoidance system architecture. In: Conference Record—IAS Annual Meeting. IEEE Industry Applications Society, pp. 493–494 (2008)
39. Song, C., Wu, J., Liu, M., Gong, H., Gou, B.: RESen: sensing and evaluating the riding experience based on crowdsourcing by smart phones. In: International Conference on Mobile Ad-Hoc and Sensor Networks, pp. 147–152 (2012)