Inter-vehicle Communication for the Next Generation of Intelligent Transport System
Trends in Geographic Ad-hoc Routing Techniques

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1. Introduction

Intelligent Transport Systems (ITS) is an information and communication technology that provides solutions mainly on reducing traffic accidents and congestions. It has been under continuous development since the early 1980s.

Despite there are some early ITS solutions that only adopt autonomous on-board equipments (e.g. ranging sensor and machine vision) to gather information from surrounding environment, most of the ITS solutions use cooperative approaches, where the traffic-related information is communicated between vehicles and/or roadside infrastructure [1]. Although an autonomous approach has an advantage that it does not rely on other participants, it has the obvious limitations in terms of vision and detection ranges as shown in Figure 1. A cooperative approach based on single or multiple hops Inter-Vehicle Communication (IVC) can better overcome the range limitations and provide a more flexible ITS solution.

![Figure 1: Autonomous approach vs. cooperative approaches](image)

However, the development of an IVC technique is not like developing other civil wireless communication techniques. The IVC has the different features as follows:

- An IVC requires more effort to deal with network delay and hard real-time event under a highly dynamic topology. Network delay and system latency cannot be tolerated in some of the ITS applications such as hazard alarming and cooperative driving.
- The size of a vehicular network can be very large in big cities. A traditional client/server system is no likely to be appropriate. The ability for having the distributed configuration is necessary.
- The density of a vehicular network is much more variable. It becomes much lower at night and on bad weather, thus an IVC need to adapt to the density changes and minimize the administrative overhead.
To develop a real-world IVC technique, these features have to be fully considered. Fortunately, comparing with other civil wireless communication one, an IVC technique can utilize two extra network supports as follows.

- **Roadside infrastructure support:** there are normally three types of IVC networks: ad-hoc, infrastructure and hybrid. A vehicular network formed as a pure mobile ad-hoc network is called Vehicular Ad-hoc NETwork (VANET). Since the distribution of vehicular network is generally along roads, it provides the opportunity for an IVC to access roadside infrastructure and gain extra supports on QoS. In a low density vehicular network, a communication through roadside infrastructures may be the only option.

- **Localization service:** an extra support that an IVC could have is the geographic information (e.g. vehicular position and direction). The information can be provided by the roadside infrastructures and the on-board satellite-based navigation systems. The power supply from on-board battery makes the support practical. The geographic information can enable the geographic IP and forwarding strategy that adapt to the frequent changes of network topology with a lower routing overhead and network delay. In fact, to use the geographic information in the development of IVC has become a common assumption.

Due to the limited length, the chapter puts more focus on the geographic routing techniques in a pure VANET, but it does not rule out the possibility of adopting the roadside infrastructure as a localization service. Although the chapter focuses on the routing aspect, it does not leave out the introduction of the techniques in wireless sub-layers because they are the foundation of designing any routing technique.

The remainder of the paper is organized as following. In the next section, the ITS projects related to IVC will be summarized. Then, we introduce the available wireless sub-layer techniques which have been developed or experimented by these ITS projects. After that, we present the main section of the chapter which explains the geographic routing techniques for VANET. In the last section, we present the open issues in developing an IVC technique and conclude the chapter.
2. IVC-relating ITS Projects

The requirements of IVC networks are different in ITS projects. The earlier ITS projects started from enabling the coordinated driving that couple vehicles at close following distances. Normally the leading vehicle with a human driver works as a base station to perform localized controls. Vehicles use pattern recognition, radar and wireless communications to form a vehicle platoon. Some projects in this period require a localized auto-organized and high-quality real-time IVC system and the typical ones are listed in Table 1:

<table>
<thead>
<tr>
<th>Periods</th>
<th>Projects</th>
<th>Countries</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980s</td>
<td>Cooperative driving project by Association of Electronic Technology for Automobile Traffic and Driving (JSK) [2] [3]</td>
<td>Japan</td>
<td>Group cooperative driving</td>
</tr>
<tr>
<td>1990s</td>
<td>CHAUFFEUR Project [5]</td>
<td>EU</td>
<td>Developing new electronic systems for coupling trucks at close following distances.</td>
</tr>
</tbody>
</table>

Most ITS projects in the early 2000s in Table 2 tried to provide the IVC-based driver assistance systems because it is easier to be implemented and more flexible in complex traffic conditions. The priority of these projects is still safety and traffic efficiency, but the additional goals like energy efficiency and comfortable driving were also considered. Moreover, because the localization technology like GPS/DGPS has been relatively mature in this stage, the position-based (or called geographic) routing techniques started to be widely used in IVCs.

<table>
<thead>
<tr>
<th>Periods</th>
<th>Projects</th>
<th>Countries</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001-now</td>
<td>eSafety Working Group [9]</td>
<td>EU</td>
<td>Work for a quicker development and increased use of smart road safety and eco-driving technologies (cut road traffic's energy consumption and CO₂ exhausts).</td>
</tr>
</tbody>
</table>
Following the successes in the previous ITS projects, large ITS projects were starting to be launched in the period of mid-2000s as shown in Table 3. Governments, international commissions and consortiums considerably increase the investment on ITS projects, especially those relating to roadside infrastructure deployment, which is the significant difference comparing with the previous period. The existing cellular towers and wireless access points are also considered to be utilized as the ITS infrastructure in these projects.

Table 3 Typical ITS projects after mid-2000s

<table>
<thead>
<tr>
<th>Periods</th>
<th>Projects</th>
<th>Countries</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001-now</td>
<td>Projects launched by/related to Car2Car Communication Consortium (C2C-CC)</td>
<td>EU</td>
<td>Increasing road traffic safety and efficiency by means of cooperative Intelligent Transport Systems with Inter-Vehicle Communications supported by Vehicle-2-Roadside Communications.</td>
</tr>
<tr>
<td>2003-2011</td>
<td>Driving Safety Support System (DSSS) related projects [11]</td>
<td>Japan</td>
<td>Reduce traffic accidents, relays information to vehicles from roadway infrastructure, advising drivers of nearby traffic lights or warning them of the approach of a vehicle or a pedestrian from a side road.</td>
</tr>
<tr>
<td>2003-now</td>
<td>U.S. Department of Transportation (DOT), Vehicle Infrastructure Integration (VII) (The project was renamed to IntelliDriveSM in 2005) [12][13][4]</td>
<td>USA</td>
<td>Develop a networked environment supporting very high speed transactions among vehicles (V2V), and between vehicles and infrastructure components (V2I) or hand held devices (V2D) to enable numerous safety and mobility applications</td>
</tr>
<tr>
<td>2004-2010</td>
<td>Smartway Project</td>
<td>Japan</td>
<td>Develop and deploy practical AHS (Advanced cruise-assist Highway System) infrastructure</td>
</tr>
<tr>
<td>2006-2010</td>
<td>Projects launched by Cooperative Vehicle-Infrastructure System (CVIS) projects launched by European Commission [15]</td>
<td>EU</td>
<td>Cooperative vehicle-infrastructure systems that create additional effective road network capacity and a more efficient utilization by vehicles</td>
</tr>
</tbody>
</table>

Although the ITS is a very active researches area, most of the existing ITS projects are still in the planning and design stage. A few experiment platforms have been constructed but there will not be a large implementation until the tested systems are reliable.

The major goals of the current IVC-related ITS projects are to improve safety, traffic management, energy efficiency, and comfortable driving. A large part of existing IVC techniques are designed base on the assumption that a vehicle can obtain geographic information. The importance of introducing roadside infrastructure in IVC system has been recognized by recent projects.
3. Wireless Sub-layer Techniques

An IVC network connection needs to be made and authenticated very quickly in ITS applications, especially for hazard alarming and cooperative driving. Many of the current wireless techniques at the PHYsical (PHY) layer and the Media Access Control (MAC) layer do not fulfill the high-speed requirement. Therefore, the large ITS projects, particularly those supported by governments and international commissions, have been investigating the related technical issues. Potential solutions especially for ITS domains have been proposed and some of them have become standards or obtain patents. The typical PHY and MAC layers techniques that have been test in real-world experiments are presented in this section.

3.1. WLAN and WPAN (up to 300 m)

The Wireless Local Area Network (WLAN) here only refers to the general Wi-Fi techniques mainly for personal usage, because technically speaking the Dedicated Short-Range Communications (DSRC) in the next section is also a type of WLAN techniques. On the other hand, the Wireless Personal Area Network (WPAN) refers to a more specific personal network for interconnecting devices (e.g. laptop, telephone and PDA) centered on an individual person's workspace. Although many researchers have used the WLAN and WPAN communication models in the IVC protocol designs and simulations, the major techniques that have been tested in real-world environments are only Wi-Fi (IEEE 802.11b [16]) and ZigBee (IEEE 802.15.4 [17] [18]):

- Currently Wi-Fi is the most popular wireless techniques. Public Wi-Fi hotspots exist throughout the many countries. IEEE 802.11b Wi-Fi has a radio range up to 100 m and data rate up to 11 Mbps (For IEEE 802.11g, it is 54 Mbps). The Wi-Fi MAC layer adopts Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with an optional RTS/CTS (Request to Send / Clear to Send) mechanism to deal with the hidden node problem. The early researches at Virginia Tech Transportation Institute in the USA tried to provide a communication solution in high mobility scenarios by using the low-cost WLAN technologies including IEEE802.11b [19]. The IntelliDriveSM project used Wi-Fi to assist with DSRC in the shorter range communications [4].

- The IEEE 802.15.4 is a typical Low-Rate Wireless Personal Area Network (LR-WPAN) standard. Comparing with Wi-Fi, IEEE 802.15.4 ZigBee has a longer outdoor radio range (up to 300 m) and requires lower power consumption. Moreover, ZigBee devices normally have a lower retail price, which is an important advantage because ITS devices should be in a lower price to enable a broader adaptability. The collision avoidance mechanism in 802.15.4 standard is also CSMA/CA. The CIVIC project [20] [21] is based on IEEE 802.15.4 and the results from real-world experiments have been published in [22].

Both Wi-Fi and ZigBee standards work at unlicensed 2.4 GHz band thus they are easy to get network interference or management overhead. Besides, the radio ranges of them are relative shorter than DSRC introduced in the next section. However, because these techniques have
been widely used in the world and proved to be generally reliable, the ITS applications built upon them can have a lower implementation cost with a relatively high-performance.

There are other WPAN and WLAN techniques have been considered to be adopted in ITS applications but they all have obvious drawbacks. For example, Bluetooth (IEEE 802.15.1) is also a low cost standard in 2.4 GHz. It has a 723 Kbps data rate and up to 10 m radio range, but it only supports 8 active devices and its network join time is too long (3 seconds). Similarly, Radio-Frequency IDentification (RFID) techniques have the problems in term of radio range and low data rate. It can be used in vehicle identification and ETC, but not for general IVC usages.

3.2. DSRC (up to 1 km)
The Dedicated Short-Range Communications (DSRC) is a set of PHY and MAC techniques specifically designed for low-latency ITS solutions. The DSRC-related IEEE standard enables one-way or two-way wireless communication channels in a range up to 1000 m with up to 27 Mbps raw data rate. It works on the licensed frequency band, but the frequency bands allocated for DSRC are not compatible in different countries:

- The early studies on DSRC were started in 1993 on the project of group cooperative driving by the JSK [2] [3] in the Japan. It utilized 5.8 GHz band for transmitting data and it employed DGPS for measuring vehicle location [23]. The Japanese national standard of 5.8 GHz DSRC band was completed by Association of Radio Industries and Businesses (ARIB) in 1995 [24].
- In Europe, the European Telecommunications Standards Institute (ETSI) has allocated a 30 MHz bandwidth in 5.9 GHz band for ITS in 2008. The main DSRC applications in Europe are in Electronic Toll Collection (ETC), but currently these applications are still not totally compatible. C2C-CC [10] is the major project in Europe to develop the DSRC-related techniques.

Based on the works of FCC ASTM E2213-02 standard, Institute of Electrical and Electronics Engineers (IEEE) started to create working groups in 2004 to develop the standards to cover the PHY and MAC layers for ITS. The standards and the related techniques are still in the developing stage. The newest results are the IEEE 802.11p [26] specifications and IEEE 1609 family of standards [27], which together are called Wireless Access in Vehicular Environments (WAVE).

The IEEE 802.11p standard at the MAC layer is an approved amendment to the IEEE 802.11a standard but with lower overhead operations. The MAC layer, frequency band and modulation of these two are very similar. For example, the MAC layer of WAVE also adopts CSMA/CA with a RTS/CTS mechanism. The IEEE 1609 standard family is built on top of IEEE 802.11p to add
definitions more details on the architecture, communications model, management structure, security mechanisms and physical access that enable a low-latency mobile ad-hoc and infrastructure vehicular networks.

3.3. Cellular Networks (more than 1 km)

A big research effort has been spent on adopting current cellular network techniques to support ITS applications. The main reasons are that the cellular network can provide much longer radio range and the cellular infrastructures have deployed in most major cities in the world. However, cellular network techniques would normally have relatively lower data rate, longer network latencies and less reliability. Three typical cellular network techniques are given as follows:

The UMTS Terrestrial Radio Access Time Division Duplex (UTRA-TDD) is a 3G cellular network technique. It operates in the unlicensed frequency band from 2.010 to 2.020 GHz. It has about 1 km radio range. The data rates are according to the speeds, such as 144 Kbps (on moving vehicle), 384 Kbps (outdoor) and 2 Mbps (indoor). The IVC based on the development of UMTS technology can minimize the cost of access medium, and guaranty the full compatibility with the 3G mobile phone. The IVC in FleetNet [6] and CarTALK2000 [7] [8] projects were developed based on the UTRA-TDD.

About the new coming 4G techniques, Worldwide Interoperability for Microwave Access (WiMAX) and 3GPP Long Term Evolution (LTE) are the only two commercially deployed candidates:

- WiMAX based on IEEE 802.16-2004 standard offers a radio range up to 50 km with a downlink data rate of 40 Mbps in a static node or 14 Mbps in a mobile node. It works in three licensed bands: 2.3 GHz, 2.5 GHz and 3.5 GHz. There were already practical ITS projects adopting WiMAX, for example the VII POC project supported by U.S. Department of Transportation has used it as backhaul purposes [28].
- The newer LTE is an evolution of the GSM/UMTS standards. The LTE standard can adopt different frequency bands from 700 MHz to 2600 MHz. It offers up to 100 km radio range and a downlink peak data rate of 100 Mbps (static/mobile). The first LTE service was launched in 2009, thus there seems no practical ITS project using it. However, comparing with WiMAX, LTE has a clearly better performance particularly in mobility features therefore it may be a better choice in the future ITS applications.

3.4. Comparison

Table 2 presents a comparison of the wireless sub-layer techniques that can be available for current or near future IVC/ITS. There are techniques that have not been presented because either they have obvious drawbacks for IVC (e.g. Bluetooth and RFID), or they are maybe too advance in the current technique conditions (e.g. satellite networks), or they have not been really experimented in real-world ITS test environments (lots of them).
### Table 4 Comparison of considerable wireless sub-layer techniques

<table>
<thead>
<tr>
<th>Name</th>
<th>Max Range</th>
<th>Max Data Rate</th>
<th>Licensed Band</th>
<th>Mobility</th>
<th>Infrastructure Necessity</th>
<th>Main Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth</td>
<td>10 m</td>
<td>723 Kbps</td>
<td>No</td>
<td>Very Low</td>
<td>No</td>
<td>- ETC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Intra-vehicle usages</td>
</tr>
<tr>
<td>RFID</td>
<td>10 m</td>
<td>500 Kbps</td>
<td>No</td>
<td>Low</td>
<td>No</td>
<td>- ETC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Vehicle identification</td>
</tr>
<tr>
<td>WLAN: Wi-Fi</td>
<td>100 m</td>
<td>11 or 54 Mbps</td>
<td>No</td>
<td>Middle</td>
<td>No</td>
<td>Low-requirement, low-cost and general-purpose usages</td>
</tr>
<tr>
<td>WPAN: ZigBee</td>
<td>300 m</td>
<td>250 Kbps</td>
<td>No</td>
<td>Middle</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>DSRC</td>
<td>1 km</td>
<td>27 Mbps</td>
<td>Yes</td>
<td>Very High</td>
<td>Customizable</td>
<td>- Safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Traffic and energy efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Comfortable driving</td>
</tr>
<tr>
<td>3G: UTRA-TDD</td>
<td>1 km</td>
<td>- 144 Kbps (vehicle) - 384 Kbps (outdoor) - 2 Mbps (indoors)</td>
<td>No</td>
<td>High</td>
<td>Yes</td>
<td>- Traffic and energy efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Comfortable driving</td>
</tr>
<tr>
<td>4G: WiMAX</td>
<td>50 km</td>
<td>- 40 Mbps (static) - 14 Mbps (mobile)</td>
<td>Customizable</td>
<td>High</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>4G: LTE</td>
<td>100 km</td>
<td>100 Mbps (static and mobile)</td>
<td>Customizable</td>
<td>Very High</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

All of the mentioned wireless sub-layer techniques have advantages and disadvantages depending on the type of ITS application and the amount of budget. DSRC is especially designed for all ranges of ITS applications, thus normally it will have a better performance. But it is a network technique still in the developing stage. However, if it is for an IVC/ITS project with small budget and tight time limit, it is more reasonable to utilize the available techniques such as Wi-Fi, ZigBee and 3G, and sometimes it may be the only choice.
4 Geographic Routing Techniques for VANET

This section presents the geographic routing techniques dedicated to the VANET in IVC/ITS applications. Firstly we discuss the features of VANET by comparing it with the regular MANETs in section 4.1. Then we address one of the main issues in geographic routing, the localization service, in section 4.2. Many related chapters just assume this service is already there, but that is not practical in real-world IVC/ITS applications. After that, we present three groups of major geographic routing techniques in VANET including the classical unicast greedy routing in section 4.3, the geocast (multicast) routing in section 4.4, the DTN-based routing in section 4.5, and the map-based routing in section 4.6.

4.1 Features of VANET

The VANET is a specific Mobile Ad-hoc NETwork (MANET). Comparing with the general-purpose Mobile Ad hoc NETwork (MANET), they have three major differences:

- The moving nodes in a VANET have much faster speed. The “mobile” of MANET sometimes just means a random static access in different positions but not really a continuously movement.
- The movement pattern of a VANET is generally limited along the road with fixed directions, but the one in a MANET is more of a randomly movement.
- The scale of a VANET is much larger than the one of a MANET. The short range sub-layer techniques like Bluetooth, Wi-Fi and ZigBee are all typical MANET techniques.

Because of the low-mobility random-pattern and small-scale features, a MANET routing would more often identify nodes by traditional IP methods, and require an end-to-end route to be found before a data delivery. The route discovery normally uses link status as a metrics to obtain the best route in a weighted graph. Then it maintains the weighted graph to adapt to topology changes. But as for a VANET routing, it is a different case. An end-to-end route could be often unavailable in a VANET. The maintenances of traditional IP and route could be very difficult. Simulations [29] [30] and real-world experiments [31] also prove the incompatibility of using MANET techniques in a VANET. Therefore, a specialized routing technique needs to be developed.

By considering the VANET and IVC features, and the extra supports from localization service and roadside infrastructure, a geographic routing can be well adapting to ITS applications. The geographic routing techniques consider the physical position of nodes (or regions) as a principle routing parameter. But just to be clear, the geographic routing is not a completely new species in routing techniques. The major difference is just that it utilizes the geographic parameter in the IP and routing processes. Some principles and strategies originally proposed by MANET routing techniques can be transformed into a geographic routing, such as the loop-free mechanism in DSDV [32], the reactive and redundancy-free mechanism in AODV [33] [34], the source routing in DSR [35], the link-reversal algorithm in TORA [36], and the zone-based (or
cluster-based) mechanism in ZRP [37]. But in this chapter, these non-geographic routing techniques will not be specifically introduced.

Although the geographic routing techniques have their advantages, they have not yet been become broadly practical in the IVC/ITS projects. Some problems have to be overcome firstly and these problems will be introduced in the following sections.

4.2 Localization
The first step of a geographic routing is localization, which is one of the main challenges in using geographic routing. Although the satellite-based navigation systems such as GPS (United States), Galileo (European Union) and Beidou (China) are becoming widely available, not all vehicles can have one. Besides, deal to the inadequate satellite number (e.g. blocked by buildings), the position may not be always accurate. The localization problems may be improved if a node can gain the supports from the roadside localization service, but some of them could be too expensive to be implemented. Besides, a practical localization service could meet a “the chicken or the egg” dilemma: to improve quality, a practical localization service may require a geographic routing technique to transmit some reference data in the first place. But to transmit the data, a geographic routing may need to acquire the correct geographic information from a localization service in the first place. However, many civil localization services and related techniques have been developed to solve the problems. While some of the localization techniques are relatively mature, it is reasonable to develop the VANET routing techniques based on geographic information.

Geographic routing techniques normally require a networking node to have three types of positions: its own position, the neighbor positions and the destination position. Each of them has the related techniques to obtain:

Boukerche [38] summarize the civil localization services that can help a node to get the position of its own:

- **DGPS**: correcting the positions from GPS based on the difference from the positions of reference stations
- **Map matching**: using the map knowledge to improve positions
- **Cellular localization**: correcting positions by the mobile cellular infrastructure
- **Image/video processing**: providing positions through roadside security systems
- **Indoor infrastructure assist**: using the signal propagation characteristics for indoor environments
- **Dead reckoning**: calculating the current position based on the last known position
- **Relative distributed ad hoc localization**: estimating the distance by the known positions of other nodes

A bigger portion of them relies on the infrastructure supports. The DGPS, video/cam localization and indoor infrastructure assist can provide a more accurate position than others, but they rely
on centralized approaches to be realized. The dead reckoning can be independently completed by a node, but it is not accurate for a longer distance.

The positions of neighbor nodes the neighbor positions are normally learned through the periodical one-hop broadcast or the reactive neighbor knowledge querying, thus this step is relatively simple. Moreover, if using a contention-based forwarding strategy, there is no need to get the neighbor positions in advance.

The main issue here is how to discover the destination position. Normally, the position of destination node (or region) is specified in the forwarding packets from a source node (original sender). In the best case (e.g. the destination position is a fixed roadside infrastructure), the source node can just get the position directly from the roadside infrastructure. In the worst cases, the source node uses the reactive simple flooding to query the destination position from all networking nodes that it can reach. Between these two cases, there are two localization techniques can be adopted, namely flooding-based localization and update and query localization. The sections 4.2.1 and 4.2.2 give more details about the two localization techniques, and we summary them in section 4.2.3.

**4.2.1 Flooding-based Localization**

*Distance Routing Effect Algorithm for Mobility (DREAM)* [39] represents a typical example of using the proactive flooding-based techniques: a node maintains a position table for the nodes that it can hear, and it tries to send its position-related information to the nodes that it can reach.

In order to control the localization overhead in flooding, the DREAM protocol considers two effects between nodes: *mobility* and *distance*. The *mobility* effect is implemented as the flooding frequency. The node with a faster speed floods more frequently. The *distance* effect refers to the phenomena that if the distance between two nodes is greater, the relative movement to each other appears to be slower (e.g. for the node A in effect the node B seems moving slower than node C in the south direction). The packet to deliver the position position-related information contains node id, position, direction and *age* (i.e. hop number). The *age* represents to the result of the distance effect. The receivers of such packet can then calculate their distance effect, and decide whether to discard the packet based on the *age* in the packet.

![Figure 2: An example to show the distance effect in DREAM](image)
Another variation of flooding-based localization technique is used in Location-Aided Routing (LAR) [40]. When nodes do not have any knowledge about the network, LAR works similarly to DSR and AODV: reactive request process, avoiding redundant requests in a flooding, and the information about route and location is contained in the packets.

Note that, both DREAM and LAR only use flooding in the destination discovery, not for the data delivery. More details about their data delivery techniques will be given in section 4.4.1.

4.2.2 Update and Query Localization

There are two major processes in update and query localization techniques: location update and destination query. The former sends out the position-related information to a subset of nodes called location server; the latter searches the location servers to get a destination location.

The update and query localization techniques can be divided into three groups based on the differences in their localization strategies, namely hierarchical [41], quorum-based [42] and home region [43] [44] localizations. Here we only introduce the first two techniques, because normally the home region localization is only used in regular MANETs and Wireless Sensor Networks (WSNs).

4.2.2.1 Hierarchical Localization

The hierarchical localization (or called hierarchical hashing-based quorum-based) normally explicitly divides nodes into a hierarchical layer structure based on the node positions, and at least a node in each layer acts as a location server that responses for updates and queries for the nodes. The hierarchical localization services can help to reduce the localization overhead and achieve the network scalability, but whether it is robust enough to nodes mobility like VANETs will need more evaluations to prove. Here we only introduce a typical protocol named Grid’s Localization Service (GLS) [41], which has the characters to be suitable for VANETs.

The GLS protocol provides a decentralized hierarchical algorithm, which can handle low-mobility nodes with a less localization overhead. If all nodes know their GPS positions and they agree on a global origin of the hierarchy as shown in Figure 3, the algorithm of GLS can be done by the nodes themselves. Besides, it is possible to further introduce the fuzzy localization in to the hashing function, thus not all nodes need to know their accurate GPS positions.

The layer in GLS is referred to as an order-\(n\) square. A number of order-\(n\) squares make up an order-\(n+1\) square as the next layer, and so on. The nodes in the same square must in each other’s one-hop communication distance, and the maximum communication distance is assumed to be two hops. Note that, the location update and destination query service does not completely rely on the rules for geographic division.

For the location update (e.g. the node 8), each node periodically deliver its ID to all one-hop neighbors in its first-order square (e.g. to node 20). Then the location is delivered to the assigned location servers in the next layer (e.g. node 1, 11, 16; maybe delivers from 59 to 16 but it is not important for the algorithm), and the process continues until the ID are delivered to the
assigned location servers in all layers (e.g. node 12, 18, 36, then node 9, 10, 53). For each square in the next layers, only one location server will be assigned. The assigned location server is the node with the least ID greater (or greatest ID less) than the ID of the source node; in the other word, the node with the closest ID is chosen. For the destination query, it uses the similar process, which tries to find the location server with the closest ID to the destination ID from its layer to the next ones (e.g. node 62 to 12, then 10), and a location server that has stored the ID of the destination will be found eventually.

The GLS protocol balances the localization overhead by evening the assigning of location servers. Moreover, because the GLS protocol delivers the location update and destination query based on layers, the localization overhead can be greatly reduced and it is predictable: if the height of the hierarchy is $O(\log(N))$, effectively the location update and destination query is delivered to $O(\log(N))$ location servers, where N is the number of nodes.
4.2.2.2 Quorum-based Localization

The quorum-based approach meaning is that all nodes in the network agree upon a mapping that maps their unique identifier to one or more quorums. The quorums respond for the specified functions of other nodes.

For quorum-based localization, it normally means that nodes sends location updates to a subset of nodes (i.e. location servers), and sends destination query to another of nodes. These two subsets of nodes must have the intersection nodes to assure a virtual connection backbone. In other cases, if two subsets of nodes are identical, they can also be called as rendezvous-based [46].

![Figure 4: An example of DS-quorum localization](image)

Here we only introduce about the classical quorum-based localization called column-row localization such as in Dominating Set quorum (DS-quorum) [42] or XYLS [45]. The DS-quorum protocol proposes an algorithm that divides a network into connected dominating sets as shown in Figure 4. The dominating set of a graph $G=(V,E)$ is the subset $D$ of $V$ where the set of vertices in $G$ is either in $D$ or adjacent to a vertex in $D$. The nodes representing the location servers are arranged in a form of columns and rows, for example, the location servers in rows may respond for the location update, and the ones in columns may respond destination query. Then, the
location update is delivered from the current location of sender to north and south, until reaching the location servers in rows. The destination query is delivered from the current location of sender to east and west, until crossing the location servers in columns, and then passes to the intersection nodes with the queried location updates. Because the DS-quorum network deliver in the column-row form, effectively the location update and destination query are delivered to $O(\sqrt{N})$ location servers.

As for used in VANETs, there are three advantages of the column-row quorum-based localizations. Firstly, they adapt well to synchronous vehicle movements on roads; secondly, they can be used to form a network backbone for mixing ad hoc and infrastructure communications; thirdly, they are able to better utilize the GPS information about longitudes (columns) and latitudes (rows).

4.2.3 Summary
In summary, the flooding-based localization could generate a high localization overhead and they are not scalable well, but they can have a low implementation complexity, and they are relatively robust in a small network section of a VANET (e.g. the short ad-hoc sections between cities). On the other hand, the update and query localization can achieve the network scalability which is suitable for a large scale VANET, but these algorithms themselves may have too much impact on localization overhead, and they are easier to affected by node failures.

4.3 Unicast Greedy Routing
The early unicast strategies started from the late 1980s are all based on a greedy forwarding strategy. The basic greedy strategies in section 4.3.1 select a next forwarder from neighbor nodes by measuring the maximum forwarding progress toward the destination position.

However, only using greedy forwarding will meet a void area situation, where there is no other node that is closer to the destination position than the forwarding node itself. The basic greedy forwarding will fail in this situation even if there is an existing end-to-end route to the void area.

The void area situation could happen frequently in VANETs, because the vehicles will not be distributed averagely following the shapes of roads. The situation could be more serious if considering the non-typical VANET sub-layer like Wi-Fi and ZigBee that has only radio range within 100 m and 300 m, respectively. Therefore, a series of recovery solutions have purposed and we present them in section 4.3.2.

4.3.1 Basic Forwarding Strategies

4.3.1.1 Next-hop Candidates
Here we can assume that the positions of a node itself and destination are known from one of the localization services. A geographic greedy routing will then forward a packet to one or more next-hop nodes with the maximum forwarding progress.
A geographic next-hop selection algorithm is normally defined in a Cartesian coordinate plane in two dimensions as in the Figure 5. The network model is assumed to be the unit disk graph where nodes can communicate within radio range $R$. The node at $s$ is the last sender and the node at $d$ is the destination. From point $s$ to $d$, it is called progress direction. The area within the radio range and from $y$-axis toward the progress direction is called progress area. An algorithm can also select the next hop in a smaller progress area, i.e., the maximum forwarding area with a margin in the form of an arc having the center at $d$. The algorithms are given as follows:

- **Most Forward progress within Radius (MFR)** [47]: This strategy selects the node with the longest projection distance in progress direction (e.g., the distance of $sm$). The longer-range transmission is favorable because it may take a packet to more hops ahead. If there is no other node as the next hop to forward a packet, MFR sends the packet back to the previous node.

- **Nearest with Forward Progress (NFP)** [48]: The node with the shortest projection distance in the progress area is selected (e.g., the distance of $sn$). The strategy favors shorter-range transmission because it may minimize transmission energy consumption (but it depends on the wireless sub-layer functions). Besides, it can have a lower probability of packet collisions if using the contention-based forwarding in the next section.

- **Distance-based Greedy (DG)** [49]: The strategy is originally proposed for wired networks. It selects a node that minimizes the distance to the destination (e.g., the distance of $gd$). Its advantage is similar with MFR.

![Figure 5: Next-hop candidates in unicast greedy forwarding](image-url)
• **Compass Routing (CR)** [50]: It is the first proposal to using the minimum angle in the next-hop selection. It selects the node with the minimum angle between the node and destination (e.g. the angle of $\alpha$). The nodes closer to the $y$-axis in the progress direction will consume more energy under this strategy.

The original NFP and CR have the problem of routing loop, but MFR and DG are loop-free [51]. A routing loop problem causes a packet circulate among certain nodes.

### 4.3.1.2 Beacon-based and Contention-based Forwarding

A **beacon-based** forwarding requires knowing the positions of one-hop neighbor nodes, which can be achieved by neighbor knowledge exchanges (i.e. beacon exchanges). When the neighbor positions have been achieved, the selection process for the next-hop node is done by the sender itself. The beacon-based forwarding has less implementation complexity, but it relies on a wireless sub-layer to provide a one-hop unicast mechanism, which is available for Wi-Fi, ZigBee and DSRC in the section 3. The neighbor knowledge exchange could cause additional routing overhead, but it can be reduced if the frequency is well controlled.

A **contention-based** forwarding does not rely on neighbor knowledge exchanges. A sender may blindly broadcast a packet, then the nodes that receive the packet self-configure if they can be the next-hop forwarders. To minimize the packet collision, the number of forwarders needs to be limited by three restrictions as follows:

- The first restriction is that only the nodes in a progress area are selected. An implementation for this restriction is relatively simple. Assuming each node knows its own position, a sender can add its position and the destination position in a forwarding packet. The nodes that receive the forwarding packet can have three required positions and then calculate whether they are the required forwarders.
- The second restriction is to limit next-hop candidates in an area that they can hear from each other, so that if a node in the next-hop candidates has forwarded a packet, the other candidates can know and stop the redundant forwarding.
- If only implementing the previous two restrictions, the node closest to the sender will normally receive and forward the packet firstly. To avoid that, a geographic forwarding need to increase the time lag by adding a timer delay function based on the algorithms in the section 4.3.1.1. For example, if the direct distance $d$ is used, the delay $t$ can be calculated as $t = a/d \times \text{MaxDelay}$, where $a$ is the parameter to adjust the advance progress, and $\text{MaxDelay}$ is the maximum delay to keep a packet before dropping it.

If a RTS/CTS mechanism is available such as the Wi-Fi and DSRC based on IEEE 802.11, the second restriction is optional. A bigger involved forwarding area in the progress area can exploit more candidate options such as in [52] [53].

For an implementation without RTS/CTS mechanism such as ZigBee, there are three restriction areas as shown Figure 6 in proposed in **Beacon-less Routing (BLR)** [54]: a circle with the diameter
equaling to the radio range $R$, a Reuleaux triangle with the maximum apex angle of 60 degree, or a sector with the same angle. Comparing their proportion with the area of radio range circle one, they can limit the forwarding area to the ratio of about 0.25, 0.22 and 0.17, respectively. A smaller involved forwarding area can reduce the possibility of packet collision. For example, the IGF [55] based on BLR implements the sector area as the addition RTS/CTS mechanism in IEEE 802.11.

![Figure 6: Optional areas in contention-based forwarding](image)

### 4.3.2 Void Area Recovery

If the progress area of a sender is a void, the forwarding packet will be blocked. The recovery solutions in this case work with the greedy forwarding to deliver the packet. We give more details on the major one, Perimeter Routing, in section 4.3.2.1, and then brief the others in section 4.3.3.

#### 4.3.2.1 Perimeter Routing

The perimeter routing can provide the best recovery solution. Although its performance relies on an ideal network condition, it can guarantee the packet delivery by only requiring the one-hop neighbor information (if an end-to-end route does exist). Besides, it can work on both beacon-based and contention-based networks.

#### 4.3.2.1.1 Planarization

Perimeter routing is a recovery solution based on planar graph, which is a type of the graph with its edges that intersect only at their endpoints. A graph representing a wireless network does not naturally form as a planar graph, thus the graph needs to be simplified by a planarization process. A non-planar graph reduces the performance of a perimeter routing, and it may cause
the routing-loop problem [56] [57]. The challenge for the planarization in real-world wireless network is that the nodes can only know the one-hop neighbor information, thus a full planarization for the whole graph is not practical.

Two notable planarization algorithms which require only the one-hop neighbor information are Gabriel Graph (GG) [58] and Relative Neighborhood Graph (RNG) [59]. For both algorithms, if any node \( x \) exists within the neighborhood ranges of both \( A \) and \( B \) (the areas with gray color as shown in Figure 7), the edge of \( (A, B) \) is removed to avoid the possible crossing edge, and so the remaining edges are \( (A, x) \) and \( (x, B) \).

\( GG \) defines the neighborhood range as a circle with a diameter as the line segment \( (A, B) \). \( RNG \) defines the neighborhood range as the intersection of two circles with radius as \( R \) and the circles are centered at \( A \) and \( B \). \( GG \) and \( RNG \) offer different densities of remaining edges (wireless links). \( RNG \) produces the planar sub-graph with fewer edges thus it reduces the routing overhead; on the other hand, \( GG \) produces the planar sub-graph with a better connectivity thus it may reduce the hop number to a destination.

![Figure 7: Planarization areas of GG and RNG (in gray color)](image)

4.3.2.1.2 Face Traversal

After the localized planarization process, the nodes get a local view of a planar sub-graph without edges crossing each other. The next strategy of perimeter routing is to adopt the right-hand rule on traversing on the borders of the faces in the planar sub-graph. The packets are forwarded face by face, and progressively get closer to the destination position.

The first version of the recovery solution using perimeter routing is proposed in [60], which includes two routing algorithms named FACE-1 and FACE-2. Both FACE-1 and FACE-2 algorithms are not very efficient on their own, but they can guarantee the packet delivery. Thus they work as the recovery solutions to incorporate with the basic greedy forwarding. Figure 8 and Figure 9 demonstrate them as the stand-alone routing process without returning to greedy forwarding. The packet in both figures is assumed to be sent from the source node \( S \) to the destination node \( D \) by a sequence of faces (e.g. from \( F1 \) to \( F3 \)).
The key rule for FACE-1 is to find the edges that intersect with the line segment from the source to the destination (e.g. $SD$), and the founded edges (e.g. $(A, B)$ and $(E, F)$) should be closer to the destination gradually (e.g. from $F1$ to $F3$, the distances $\text{dist}(S, D) > \text{dist}(p_1, D) > \text{dist}(p_2, D)$). Before a packet is passed to the next face, the packet must do a complete traversal thought the border of a face and then return to the initial point (e.g. $S, A$ or $F$).

Based on FACE-1, Adaptive Face Routing (AFR) [61] purposed a variant algorithm. The source node in AFR initially estimates a boundary of FACE-1 as an ellipse with foci on source and destination. When a packet reaches the border of the ellipse, the packet is delivered back to the last initial point. The packet is then sent to the initial point of next face. If the routing path is blocked because the ellipse is too small, the packet is sent back to the source node, and the size of the ellipse is increased. If $c$ is the cost of the best path in FACE-1, AFR can achieve a worst case cost of $O(c^2)$. Besides, GOAFR+ [62] purposed an integration of the greedy forwarding and AFR.
On the other hand, FACE-2 is a modified version of FACE-1. When a packet is passed to the node with an edge intersecting with the line segment, $\overline{SD}$, the packet is delivered directly to the adjacent face instead of returning to the initial point (e.g. from $B$ to $F$, instead of back to $S$). **Greedy-Forward-Greedy (GFG)** is a geographic routing algorithm proposed in [60], which adopts GG for planarization.

Another well-known beacon-based geographic routing protocol, named *Greedy Perimeter Stateless Routing (GPSR)* [63], implements a recovery solution similar to FACE-2. GPSR proposes the protocol-level details for face routing and an alternative planarization algorithm RNG. When switching faces by GPSR, the packet is always delivered through the first edge of the next face by adopting the right hand rule. Then, the next edge is searched by the counterclockwise direction from the last edge. The first edges must be recorded in the transmitting packet until it reaches the next face in order to avoid the routing-loop problem.

**Greedy Perimeter Coordinator Routing (GPCR)** [64] is an improved version of GPSR. It utilizes the roads and streets as a communication backbone because they naturally form as a planar graph. The greedy and perimeter routing in GPCR is only preformed when a packet reaches the junctions. Other than that, the packet is forwarded along the road until it reaches the next junction. Therefore, GPCR is more efficient than the GPSR in an urban area.

The open issue of the recovery solutions is that they rely too much on an ideal wireless network condition, more precisely, the radio range of these solutions is assumed to be uniform as $R$ in a unit disk graph. However, the realistic radio range is often to be irregular because of the differences in wireless medium densities, link errors and inaccurate positions. Some solution were proposed for the non-ideal network conditions, for example, CLDP [56] uses an additional proactive message for planarization, and GDSTR [65] use the traversal of a hull spanning tree (an alternative technique of planarization). However, the former increases the routing overhead significantly; the latter loses the localizable advantage in geographic routing.

### 4.3.3 Other than Recovery

The techniques in this section can be used if a void area recovery is unavailable. There are three groups of solutions including dropping a blocked packet, sending it back, or exploiting more hops in advance.

Dropping the blocked packets can be an option only if 1) the nodes are generally moving and a resend mechanism is available, or 2) a multi-path routing is already used so the packet is supposed to reach a destination in the other path. SPEED [66] is a beacon-based solution, which considers dropping the blacked packet for reducing the traffic congestion. Each node in SPEED records the average delays to destinations in its neighbor table. When meeting a void area, the delay is marked as $\infty$. The neighbors then get the notice for the void area by the so-called *backpressure beacon*.

Another suggestion is to send a blocked packet back to the last forwarder. The failing routing path will be marked, thus the new greedy forwarding can look for another path and avoid
routing-loop. If the mobility of nodes is considered, any node in the similar position of the last forwarder can be used as a backtracking node. Furthermore, GDSTR [65] maintain a spanning tree where each node has an associated convex hull that contains within it the locations of all its descendant nodes in the tree. When a void area is found, the block packets are routed upwards in the tree until finding a node whose convex hull contains the destination.

In a beacon-based forwarding, a solution is to exploit more hops neighbor information in advance. The result in [51] shows that if two-hop geographic information such as GEDIR, DIR and MFR is available for each node, the void area problem can be reduced. The trade-off for the two-hop geographic information is an additional routing overhead.

4.4 Geocast (Multicast) Routing
The geocast forwarding steps are similar to the contention-based forwarding, but the destination in geocast more often to be a geographic cluster. If the destination is only a single node, when packets reach the border of the cluster that contains the destination node, the transmitting mode can be switched back to the unicast mode.

Moreover, the geocast forwarding steps can be assisted with two other techniques: hierarchy and flooding. The hierarchical geocast (e.g. GeoTora [67] and GeoNode [68]) forward packets cluster by cluster, thus it can reduce routing overhead and increase network scalability. However, the trade-off of these advantages is an overhead in cluster division. For a small area IVC built on IEEE 802.11-based Wi-Fi or DSRC, the cluster division could be too short-lived to worth creating. The hierarchical geocast may be only suitable for a large area IVC based on 3G or 4G.

The following sections only describe the non-hierarchy flooding-based geocast techniques for VANETs. Under this context, the geocast applications are only for distributing emergency messages, for example, to deliver a collision warning to all approaching vehicles and nearby junctions. In the following, we will introduce two typical flooding-based geocast techniques in section 4.4.1 and then the related geocast techniques for VANETs in section 4.4.2.

4.4.1 Restricted Directional Flooding
DREAM [39] and LAR [40] are two broadly adopted geocast protocols. They both adopt the restricted directional flooding in their data transmission, but their restricted areas are different.

After the localization steps of DREAM and LAR introduced in section 4.2.1, assuming a source node $S$ in DREAM or LAR has known that the destination node $D$ is in the position of $(x_d, y_d)$ at time $t_0$, and that the current time is $t_1$, the node can then restricts the direction and area of the next flooding as shown in Figure 10. The key scheme for both protocols is to assure that a packet is sent to an expected region that the destination node will be there when the packet reaches the expected region.
Both DREAM and LAR expect the node D is in the circle area centered at \((x_d, y_d)\) with the radius of \(r = v_{\text{max}}(t_1 - t_0)\) (e.g. the expected region (zone) are the same circle area in the north-east from node S), but the next steps are different:

- For DREAM, the nodes involved in the flooding process are the ones within the forwarding angle \(\alpha\) defined as \(\alpha = \arcsin\left(\frac{r}{L_{sd}}\right)\), where \(L_{sd}\) is the distance between nodes S and D.
- The LAR (scheme I) defines a request zone as a rectangular, where only the nodes in the rectangular floods the data packets. If a nodes S is outside the expected zone, the rectangular is within \((x_s, y_s)\) and \((x_c, y_c)\). If a nodes S is inside the expected zone, the minimum boundary of the request zone cannot be smaller than the expected zone. The LAR (scheme II) further defines that only the nodes with the shorter distances to destination node can be involved in the next-hop flooding process (e.g. from the node I, J to K).

\[
\begin{align*}
r &= v_{\text{max}}(t_1 - t_0) \\
\end{align*}
\]

![Figure 10: Flooding areas in DREAM and LAR](image)

### 4.4.2 Flooding-based Geocast for VANETs

Two earlier examples of flooding-based VANET geocast protocols are the geocast scheme in [69] and the IVG [70]. The basic strategies of them are similar:

- Firstly, when accident happens, an alarm message will be sent out to all the vehicles that will be affected by the accident. For example, if the accident is in a roundabout, only the vehicles driven toward the roundabout will receive the alarm. The destination
area that contains the alarmed vehicles is called critical area. If vehicles know their GPS information, the critical area can be defined easily.

- Secondly, when the alarm message is spread in the critical area, not all the nodes need to be involved as relay nodes. The method to limit the number of relay nodes is the same method as in contention-based forwarding (in section 4.3.1.2).

Besides, there are other geocast algorithms and protocols for VANETs are similar to these two earlier examples but with unique features:

- Cached Geocast in [71] proposes to include caching at the routing layer to deal with the situation of high velocities in VANETs. The small cache can help to improve the problems of neighbor selection and void area in the geocast forwarding.
- Urban Multi-hop Broadcast (UMB) [72] redefines the RTS/CTS mechanism in IEEE 802.11 standard to address the problems of broadcast storm, hidden node, and reliability problems of multi-hop broadcast in urban areas. The UMB divides the road into segments in the direction of dissemination, and only one vehicle in each segment is on duty of forwarding and acknowledging the packets.
- Abiding Geocast [73] is a specific geocast technique. The abiding geocast can be used to send messages to a fixed geographical area (e.g. the warning of an icy road in winter). Besides the regular approach such as the periodical delivery, Abiding Geocast provides three more options: a server approach, a node election in the destination region, and a neighbor exchange solution.

4.5 DTN-based Routing

Delay Tolerant Network (DTN) is an extreme case of MANET. VANET can be treated as a form of DTN. The distinguished feature of DTN is that the end-to-end connectivity between source and destination in DTN is assumed to be frequently broken due to network partitioning.

The earliest research on DTN routing mostly use the flooding-based techniques, but a more recent research direction tries to utilize the movement feature of nodes instead of adapting to it. That is why the recent DTN techniques are very suitable for VANETs.

This section provides two interesting DTN-based routing options that utilize the movement feature in VANETs: Last Encounter Routing (LER) [74] [75] and Carry-and-forward Routing [76].

4.5.1 Last Encounter Routing

An example of Last Encounter Routing (LER) is a routing algorithm called Exponential Age Search (EASE) [74] [75]. The recent application of LER is in the FleetNet project, which tries to build a virtual flea market over VANET. The customers express their demands/offers by smart phones, PDAs and laptops within a VANET.

The paper [74] first proposed a movement-based localization service, and it shows that it is possible to only use the node mobility to disseminate destination location information without using any flooding-based method. In other word, only "free" information about the local
connectivity to neighboring nodes is adopted. Then, a simple routing algorithm named EASE was proposed to evaluate such localization service. The interesting conclusion about EASE is that the collections of last encounter histories at network nodes contain enough information for a geographic routing protocol to route packets.

For the part of localization service, each node in EASE maintains a Last Encounter Table (LET), which contains three fields including Node ID, Location and Time. If a node $i$ meets a node $j$ at position $P_{ij}$, node $i$ records an entry as Node ID equaling $j$ and Location equaling $P_{ij}$. Time for the entry is the time elapsed since the encounter at $P_{ij}$.

As for the routing part, the principle steps are as follows: when a source node tries to send a packet, the source node searches its neighbors until finding a neighbor who meets the destination in the latest time based on the information of LET. Then the packet is routed toward the latest encounter location. The process is continuing until the packet reaches the destination node. For example, the vehicle $S$ tries to send a packet to vehicle $A$ as shown in Figure 11. In its current radio range, the vehicle $B$ uses to meet the vehicle $A$ at the location of $B_2$. If the location $B_2$ available on $B$ is newer than any other locations information that the vehicle $S$ can get, the packet is sent to the location $B_2$. The EASE made no assumptions about how to route the packet toward a latest encounter location, and any geographic routing protocol can be used here. The disadvantage of EASE is the delivery is easy to fail in a practical network when the network just starts up, or where there is a limited radio range thus the number of neighbors is too small.

![Figure 11: An example of the routing path by EASE](image)
4.5.2 Carry-and-forward Routing

Carry-and-forward is a new concept proposed in [76]. The idea is as the name suggests: when a routing path does not exist for a packet, the last receiver can carry the packet, and forward the packet to the new receiver until some conditions meet.

An example protocol adopting the carry-and-forward concept is Vehicle-Assisted Data Delivery (VADD) [77]. A moving vehicle in VADD carries a packet and forwards it to the next vehicle in the intersection of roads. In the order word, the routing paths in VADD are the exact shape of the roads. Moreover, VADD predicts the mobility of other vehicles, which follows the traffic pattern and road layout. A routing decision is based on the result of such prediction. The experimented routing decisions are based on location (L-VADD), direction (D-VADD), multipath direction (MD-VADD) and hybrid (H-VADD). The H-VADD protocol has much better performance and it can avoid the routing-loop problem.

![Figure 12: An example of the routing path by GeOpps](image)

Geographical Opportunistic Routing (GeOpps) [78] is another carry-and-forward protocol, where requires navigation information of other vehicles to predicts the mobility of other vehicles. By knowing the navigation information, the node in GeOpps knows the paths of other vehicles when it tries to forward a packet, then a decision can be made by comparing the nearest point
of these path to the destination one. For example, the vehicle $S$ in Figure 12 tries to find a routing path to the gas station at $D$. Two vehicles, $A$ and $B$, are in the radio range of $S$, and they will be driven from $A_1$ to $A_3$ and from $B_1$ to $B_3$, respectively. The nearest point of these two routing path is $A_2$, thus $A$ becomes the new relay in the routing path. The GeOpps in theory can get a better result than VADD, but the navigation information utilized in GeOpps is mostly private in VANETs.

### 4.6 Map-based Routing

Maybe we can call the map-based routing as a semi-geographic VANET technique. This technique does not directly use the hop-to-hop querying and forwarding as in previous sections; instead, they use a global road map provided by roadside infrastructure for calculating the shortest path. Because the map-based routing relies heavily on the supports from roadside infrastructure, it is not really a pure VANET routing technique. We provide a brief here because this technique can be very practical in a metropolis area. Moreover, the simulation results [79][30] show that the map-based technique can significantly outperform the techniques without using road map.

*Geographic Source Routing (GSR) [80]* is a typical example. It uses a *Reactive Location Service (RLS)*, which has some similarity with the localization service in DREAM but in a reactive approach, to obtain the destination position. Then, it calculates the junctions in the road map that will be used in traversal by using the Dijkstra’s shortest path algorithm in a weighted graph, where the vertices are junctions and the edges are streets. The forwarding process between junctions is position-based.

Because the GSR only uses a static road map for its calculation, the obtained route may be a road without enough passing vehicles to be forwarding nodes. *Anchor-Based Street and Traffic Aware Routing (A-STAR) [81]* improves the GSR by adding a traffic awareness process, which utilizes the city bus paths as an overlay map in order to identify the truck roads with higher connectivity.
5 Conclusion and Open Issues

It is still an ongoing work for many research projects to develop a reliable IVC for ITS applications to fulfill the requirements on safety, traffic management, energy efficiency and comfortable driving. It is really a difficult task because of three unique features of vehicular network: high mobility, large scale and variable density. Great research efforts have been putting in this area by the schools, governments and consortiums. Although there are many potential solutions, the practical one has not yet been found.

This chapter is mainly about the routing techniques in IVC/ITS applications, and we focus more on introducing the practical VANET routing techniques that can be used by current or near future. The wireless sub-layer techniques on PHY and MAC are also presented in this chapter, because they are the foundations of building any practical routing technique.

The main body of the chapter gives a comprehensive survey on variant geographic routing techniques, because by considering the development of localization services, the geographic routing is quite clear to be the best suitable solution for IVC/ITS applications. The survey presents the main research direction in the geographic routing techniques, the unicast greedy routing, with three additional or substitutable techniques including geocast, DTN-based and map-based ones.

The chapter has introduces the main open issues and new techniques in these geographic routing techniques along with the one in localization service, but there are still many of them that have not been fully addressed, such as the security problem in IVC/ITS, the conversion between IPv4/IPv6 and geographic position, the location-aware transport layer techniques, the QoS problems in low-cost sub-layer techniques. The research outcomes of these areas will surely improve the reliability and efficiency in IVC/ITS applications.
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