Journal of Network and Computer Applications 36 (2013) 685–697

Contents lists available at SciVerse ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Position-based routing in vehicular networks: A survey

Sardar Muhammad Bilal *, Carlos Jesus Bernardos, Carmen Guerrero

Department of Telematics Engineering, CARLOS III University, Madrid, Spain

ARTICLE INFO

Article history:
Received 12 July 2012
Received in revised form
28 November 2012
Accepted 12 December 2012
Available online 31 December 2012

Keywords:
Forwarding strategies
Position-based routing
Vehicular ad hoc network
V2V and V2I communication

ABSTRACT

Routing in vehicular network is a challenging task due to network partitioning, high vehicular speed, and city environment characteristics. These characteristics results in degraded performance in traditional routing protocols. Traditional routing protocols, addressing the issues of mobile ad hoc network, are applicable for MANET applications. Position-based routing protocols, which are mostly based on greedy routing, are more suited to highly dynamic and mobile network. In this paper, we survey state of art routing protocols previously used in vehicular networks, present open research challenges and possible future direction. We categorize protocols into two categories based on their communicating mode (vehicle-to-vehicle, vehicle-to-infrastructure) irrespective of their simulating environment (highway, urban). Both vehicle-to-vehicle and vehicle-to-infrastructure communication provides connectivity based on multi-hop paradigm in a seamless way. We discuss pros and cons for routing protocols belonging to each category. By doing qualitative comparison of routing protocols, it is observed that hybrid communication would be the better choice for both communication mode operable in either a city environment or an open environment.

1. Introduction

Vehicular ad hoc networks are kind of mobile ad hoc networks which are used to provide communications between vehicles. VANETs are self-organized networks in which vehicles communicate with each other without presence of any prior infrastructure resulting in reduced deployment cost (Vehicle Safety, 2005). IEEE 802 committee (Bilstrup., 2007) defined wireless communic ation standard, IEEE 802.11p (Jiang and Delgrossi, 2008), used for safety on the road and many other vehicular applications. The Federal Communications Commission (FCC) has allocated 75 MHz of bandwidth, which operates on 5.9 GHz for short range communications between vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure communication (V2I). VANETs use dedicated short range communication (DSRC) (Cseh, 1998) for both V2V and V2I. The range of DSRC is 1000 m which is suitable for both V2V and V2I.

VANETs support a number of applications ranging from traffic safety to entertainment (Vehicle Safety, 2005; Zimmer, 2005; Kargl, 2006; Mahlknecht Madani). Moreover, vehicular ad hoc network is core element in the development of Intelligent Transportation System (ITS) applications. ITS aims to develop applications related to vehicular safety by providing vital information related to road and traffic at the right time (Branscomb and Keller, 1996) to the drivers. By providing right information at the right time can be useful in preventing traffic accidents. Such information can be collected either by V2V or V2I or both. Mostly, accident happens due to incomplete information of road conditions including traffic signals, speed, and neighbor vehicles location. One of the major initiatives of ITS is to provide the necessary information from the surrounding of the driver. This information can be used to avoid accidents, predict dangerous scenarios, warning of hazards, condition of roads, and position of neighbor vehicles. Vehicles share surrounding information with each other and with infrastructure to make it available for other vehicular ad hoc networks. This information is communicated through the use of multi-hop paradigm. In literature, number of routing algorithms is based on multi-hop communication. These routing algorithms also consider different characteristics of vehicular communication, for instance, highly dynamic network, frequent change in vehicular network topologies, high speed of vehicles and predictable mobility. Vehicular characteristics vary from rural to urban environment. Mostly routing protocols consider either rural or urban communicating environment but not both. Thus, in either environment, information is collected from surrounding and provided to other vehicles or infrastructure by the use of V2V or V2I, respectively.

Our main contribution in this work is that we selected some well-known routing protocols from each category and study their strengths and limitations. Here we aim to survey the position-based routing protocols for both V2I and V2V communication.

* Corresponding author. Tel.: +92 334543 4922.
E-mail addresses: sbilal@it.uc3m.es, smb1118@gmail.com (S.M. Bilal), cjbc@it.uc3m.es (C.J. Bernardos), carmen.guerrero@it.uc3m.es (C. Guerrero).

1084-8045/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jnca.2012.12.023

We divide protocols into two categories based on their communicating mode (V2V, V2I) irrespective of their simulating environment. We discuss pros and cons for routing protocols belonging to each category. We find out through qualitative comparison of protocols that hybrid communication, which involves both communication modes, proves to be a better choice. We also address V2V method for estimating vehicular density and highlight its issues and present a solution. To the best of our knowledge, this is the first survey describing state of the art routing protocols for both V2V and V2I. Most of the survey papers consider routing in either V2V or V2I but not both. Our work considers both mode of communication; by highlights the problems with each of them and also proposes possible future direction.

The rest of the paper is organized as follows. Section 2 explains the characteristics and architecture of vehicular networks. It also explains forwarding strategies used in vehicular networks. Then we will explain the position-based routing protocols for V2V and V2I in Sections 3 and 4, respectively. In Section 5, we will explain the methodology for estimating vehicular traffic density. Section 6 and 7 will be based on discussion and open issues in vehicular communication and then finally, we conclude the paper in section 8.

2. Back ground

The characteristics and design architecture of vehicular communication makes a vehicular communication much more challenging. Some of the characteristics along with design architecture are describe below:

2.1. Characteristics of vehicular networks

In vehicular communication, information can be disseminated or collected through utilizing existing infrastructure or ad hoc fashion or by combining both techniques. Vehicular network can be broadly classified into three categories (Santos et al., 2005) i.e., cellular, ad hoc, and hybrid.

Cellular or WLAN-based vehicular network are designed to support infotainment related applications (Cseh, 1998; Festag et al., 2008), for example, downloading data, web browsing, getting latest news, parking information, and traffic information. Such type of network is called pure cellular or WLAN and is shown in Fig. 1. Communication in such a network is based on vehicle-to-infrastructure paradigm. Vehicles communicate with existing infrastructure, for example, base station to disseminate or obtain useful information. Although, Cellular/WLAN-based networks support wide range of vehicular applications, they still suffer from one major drawback and that is the requirement of fixed infrastructure deployment. This problem is solved by ad hoc networks where information is propagated without the requirement of specialized infrastructure as shown in Fig. 2.

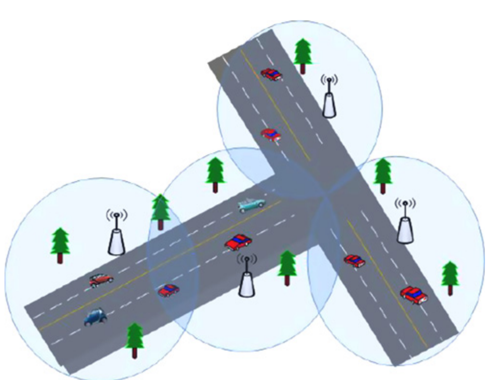

Fig. 1. Pure cellular/WLAN.

This type of network is often called vehicular ad hoc network (VANETs) and is based on vehicle-to vehicle communication. Vehicular ad hoc networks are self-organized network where packet is delivered by multi-hop fashion. Although, ad hoc networks do not require fixed infrastructure support but vehicles limited transmission range and high mobility causes rapid topology changes (Lochert et al., 2005). Such rapid topological change not only causes network partitioning but also leads to partitioning and routing link failures. Fig. 3 shows the hybrid architecture; a combination of cellular and ad hoc networks. Pure ad hoc network suffers from network partitioning and mobility.

One solution is to deploy the access points along the road. Unlike ad hoc and sensor networks, energy is not an issue because vehicles have rechargeable source of energy. On the other hand, cellular network based on centralized architecture in which traffic information is collected from the road through access points. These access points then process the acquired information and make it available to the driver. As centralized approaches are based on fixed infrastructure, cost is one of the major issues. Such cost could be hardware cost, installation cost, operational cost and maintenance cost. Another issue with fixed infrastructure is that coverage is limited to only those areas where there are access points. Those areas where access points are not installed are out of range, and hence information cannot be collected or provided. This leads to the design of hybrid network able to communicate via V2V as well as V2I links.

As the nodes are vehicles in vehicular network which move with greater speed and move along specific path like roads, so the movement of vehicle is constrained by the layout of roads as well as by the traffic regulations. Furthermore, speed of vehicles varies from one communication environment to other. Vehicles are at

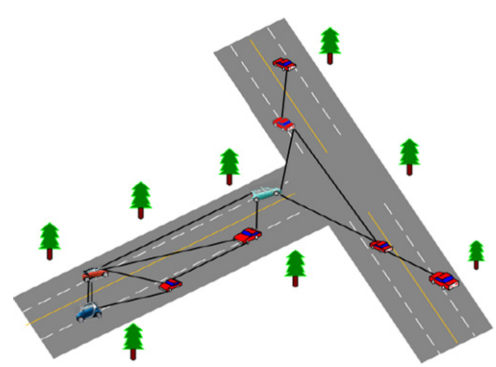

Fig. 2. Pure ad hoc network.

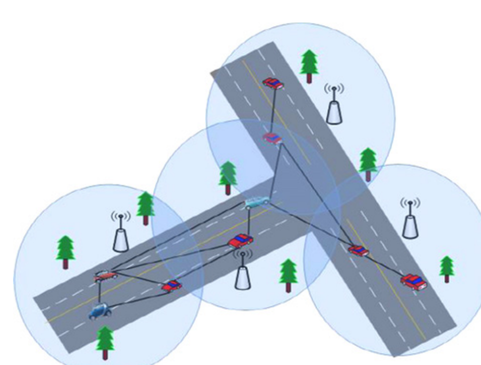

Fig. 3. Hybrid architecture.

high speed in highway traffic scenarios than in city environment. In a high way traffic scenario, there are no radio obstacles and nodes communicate with others within its radio range. While in city environment, there would be radio obstacles comprising of buildings, trees, and other obstacles. Routing in city environment is relatively complex than routing in highways. Above mentioned characteristics and design architecture of vehicular communication makes a vehicular communication much more challenging.

2.2. Forwarding strategies of vehicular networks

The dynamic nature of vehicular communication, high speed of vehicles, and mobility results in degraded performance in traditional routing protocols.

Traditional ad hoc routing protocols addressed the issues of mobile ad hoc network and are applicable for MANET applications. They suffer from high mobility and dynamic nature of vehicular communication. It has been proven that position-based routing protocols are more suited to highly dynamic and mobile network. They are more scalable and outperform tradition ad hoc routing protocols (Santos et al., 2005; Wang et al., 2005; Liu et al., 2004; Fubler et al., 2003). Currently, there are different forwarding strategies available for position-based routing protocols in literature. Normally, each vehicle maintains neighbor table (speed, direction, its geographic position) which will exchange periodically with its neighbors. Based on neighbor table, source vehicle implements its forwarding strategy and selects its next hop to forward the packets. The forwarding selection criterions are as follows (Bernsen and Manivannan, 2008; Cha et al., 2012; Fonseca and Vazão, 2009).

2.2.1. Greedy forwarding

According to the scenario depicted in Fig. 5, if greedy forwarding strategy is used then, source node forwards the packets to a node closest to the destination ‘D’. In this case ‘S’ sends packet to ‘A’.

2.2.2. Improved greedy forwarding

In this case, source node first consults its neighbor table and computes new predicted position of all its neighbors based on direction and velocity and then selects a node which is closest to the destination. ‘S’ computes new predicted position of its neighbors and suppose at time $t2$, vehicle ‘B’ overtakes the vehicle ‘A’, then ‘S’ selects ‘B’ as its next hop instead of ‘A’.

2.2.3. Directional greedy forwarding

Directional greedy approach only considers those nodes which are moving towards destination. It selects a node which is moving towards destination and is closest to the destination. Thus, it selects vehicle ‘B’ as its next hop.

2.2.4. Predictive directional greedy forwarding

In this strategy, forwarding node maintains the information of its 2-hop neighbors. Before forwarding the packet, forwarding node consults its neighbor table and computes predicted position of all its neighbors (one-hop and 2-hop neighbors) and then selects a node whose one-hop neighbor is moving towards the destination and is closest to the destination. In this case, ‘S’ selects vehicle ‘A’ because its one-hop neighbor ‘C’ is moving towards destination ‘D’.

3. Vehicle-to-vehicle routing

It is worth mentioned here that we will focus on position-based routing protocols. In literature, one can find number of survey papers on vehicular ad hoc network (Wai et al., 2008; Lee et al., 2012; Kakarla et al., 2011; Preetida and Sanyal, 2012; Bernsen and Manivannan, 2008; Cha et al., 2012) but we focus on analyzing the position-based routing protocol which seems to be the best choice for routing. One can even find survey on position-based routing protocols (Bernsen and Manivannan, 2008; Cha et al., 2012; Raw and Das, 2011) but they are only restricted to V2V communication; they don’t consider position-based routing in V2I communication. Authors in Fogue et al. (2012), Wai et al. (2008) evaluates messages dissemination techniques and (Raw and Das, 2011) presents current status of VANETs. This work considers both mode of communication, highlights the problems with each one of them and also suggests possible future direction. We classify the routing protocols into two category; V2V routing protocols and V2I routing protocols as illustrated in Fig. 4. In this section, we will describe V2V routing protocols.

The usage of digital maps, GPS receivers, and a navigation system in modern vehicles inspired the study of position-based routing for vehicular network. Most of the position-based routing protocols assume that each vehicle equipped with GPS device in order to finds its own geographic position. These protocols also assume the presence of location services. Location services provided geographical position of destination vehicle. In past, numerous location services have been proposed, for example, grid location service (Li et al., 2000) or hierarchical location services (Kiess et al., 2004). Without the use of location services, it becomes very difficult for forwarding vehicle to find the position of destination vehicle. Ad hoc routing protocols like AODV (Perkins et al., 2002) and DSR (IETF, 2007) show poor performance because these protocols are not able to discover, preserve, and update routes quickly enough. Connection established by using three-way handshake takes time which is not ideal for dynamic networks like VANETs.

Various vendors provided navigation system in today’s modern vehicles. Navigation system contains pre-loaded digital maps through which street level navigation information can be extracted. Through the use of navigation system, different junctions or anchors are identified. Position-based routing protocols use these junctions to apply different routing algorithm like Dijkstra. Position-based routing protocols like GyTAR (Jerbi et al., 2007) and E-GyTAR (Bilal et al., 2011) also consider the presence of distributed mechanism for vehicular traffic estimation. Vehicular traffic estimation technique like, IFTIS (Jerbi et al., 2007), provides vehicular traffic density between two anchors which help to determine which street is congested in term of number of vehicles.

Greedy Perimeter Stateless Routing (GPSR) (Karp and Kung, 2000) is designed to address the issues of open environments and shows improved performance compared to tradition ad hoc protocols. This is because in GPSR, there is not route discovery mechanism prior to data transmission. Nodes only know the geographical opposition of their neighbors through beaconing. Packets are marked with the position of destination. GPSR uses two routing strategies to forward the packet towards destination; Greedy forwarding and perimeter forwarding or face routing. GPSR uses greedy forwarding if the forwarding vehicle finds a suitable neighbor along the shortest path. If forwarding vehicle is the closest one to reach destination, then GPSR shifted to perimeter forwarding in which case it uses right hand to rule to select next hop. Fig. 6 demonstrates the face routing where source S wants to communicate with destination D. S computes the shortest path to reach D, it sends the packet to vehicle A. As the packets are marked the location of destination, so, when the packet reaches to vehicle A, vehicle A forwards the packet to next hop along the shortest route towards destination. The forwarding vehicle A cannot find any other closest vehicle in its vicinity

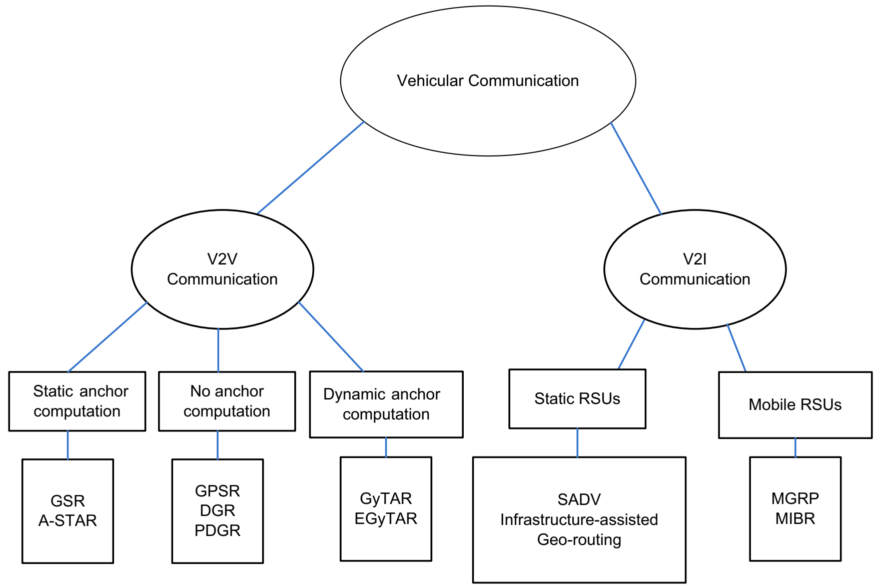

Fig. 4. Classification of routing protocols.

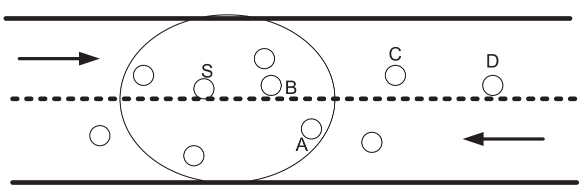

Fig. 5. Forwarding strategies.

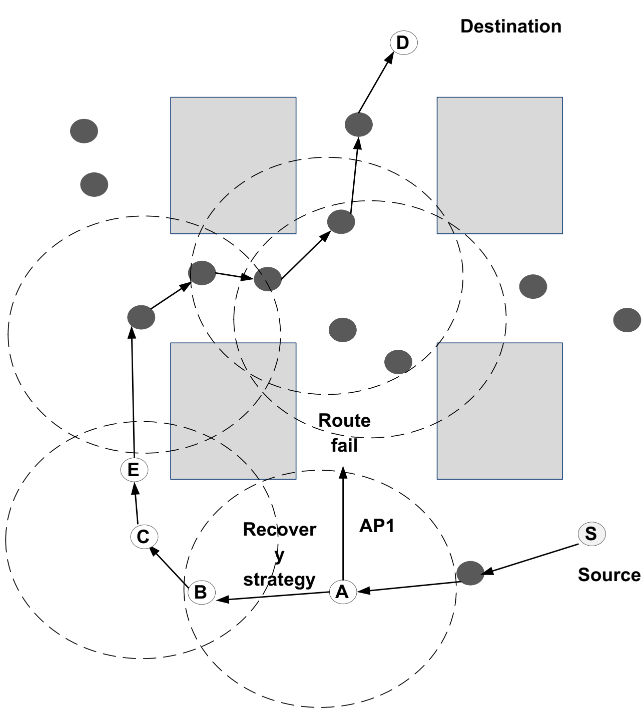

Fig. 6. Recovery strategy in GPSR.

except itself (local maximum) to reach D. When local maximum occurs, GPSR shifted to face routing. In face routing, forwarding vehicle A tries to find a route to reach D by using right hand rule. In this case, A forwards the packet to vehicle B. On reaching the packet to vehicle B, it computes next hop (towards destination). If there is a neighbor who is closer to destination than itself, i.e., vehicle C, packets are again forwarded in greedy manner. So, packet is forwarded to C and vehicle C finds vehicle E closer to destination and sends it a packet by greedy manner. Solid line shows the path taken by GPSR is shown in Fig. 6. The major advantage of GPSR lies in determining the geographical knowledge of its neighbors through beaconing. A forwarding vehicle selects next hop on the basis of local optimal which is geographically closest to the destination.

The recovery strategy of GPSR is inefficient and time consuming especially for highly dynamic nature of vehicular ad hoc networks. It is best suited to open environment with evenly distribution of nodes but it suffers in a presence of obstacles. When applied in city environment, it shows poor performance (Lochert et al., 2003, 2005; Liu et al., 2004; Fubler et al., 2003). This is because direct communications between nodes are difficult to establish under the presence of obstacles like buildings and trees. It first builds the routing topology by using planarized graph and then forward packets by using greedy or face routing which causes delay. Sometime, it forwards packets to wrong direction which causes even more delay in highly dynamic network.

Geographic Source Routing (GSR) (Lochert et al., 2003, 2005) is specifically designed for routing in city environment to overcome the disadvantages of GPSR. There are four main issues that limit the GPSR performance; network disconnection, too many hops, routing loops, and wrong direction. Perimeter forwarding limits the advantage of greedy forwarding especially in city environment i.e., forwards the packet to the vehicle which is closest to the destination. Instead, it traverses each node which increases end-to-end delay and hop count (Seet et al., 2004) as shown in Fig. 6. Vehicle B can forward the packet directly to vehicle E but it forwards the packet first to vehicle C and then vehicle E, even vehicle E lies within its communication range.

Vehicular ad hoc networks are highly dynamic and their dynamic nature poses issues like routing loops and traversing of too many hops to reach destination (Karp, 2001; Karp and Kung, 2000). During perimeter forwarding, next hop is selected purely on the basis of right hand rule even there are alternative routes available which are the shortest than a route computed by right hand rule. This again reaches the destination through traversing many hops. In GSR, source S uses city digital map to find shortest path towards destination D via Dijkstra shortest path algorithm. The shortest path composed of sequence of junctions and each packet from S must follow computed sequence of junctions to reach D.

Source S computes the position of destination D via reactive location services (RLS) (Camp and Boleng, 2002). Greedy forwarding is used to forward data packets between two involved junctions. It uses carry and forward strategy for the packets gets stuck in local maximum problem. The drawback of GSR is that the shortest path is not the optimal path since it does not consider vehicular traffic on the street. Furthermore, it uses fixed junction selection mechanism where source S at once computes sequence of junctions which the packet must traverse to reach D. This result in under performance in highly dynamic networks as junction selection mechanism should be dynamic based on vehicular traffic, road width, shortest path, and other metrics.

Anchor-based street and traffic aware routing (A-STAR) (Seet et al., 2004) is operable in city environment. It removes one of the drawbacks of GSR by taking into account the consideration of vehicular traffic on the street. Consideration of vehicular traffic on the street is based on number of bus lines that road possess and then assigns weight to each street accordingly. The more bus lines a road possess, the less weight it is assigned and vice versa. A digital map facilitates computation of anchors or junctions by using Dijkstra shortest path algorithm. Relaying of packets from source to destination is based on greedy forwarding. It introduces new recovery strategy for packets get stuck in local maximum problem.

The street at which local maximum occurred is marked as "out of service" for the short duration and this information is propagated throughout the network so that other data packets avoid "out of service" street. New anchor paths are calculated at the point of local maximum. Traffic awareness along with new recovery strategy make A-STAR performs better than GSR and GPSR in city environment. A-STAR routing protocol is traffic aware which accounts number of bus lines but it does not take into account vehicular traffic density (number of vehicles on the street). Moreover, most of network traffic is shifted towards major streets (number of bus lines), which induces bandwidth congestion. Secondary streets are seldom selected even these streets provide better connectivity and may provide optimal path.

Directional greedy routing (DGR) (Gong et al., 2007) is a position-based routing protocols for vehicle-to-vehicle communication operable in open environment. As it is designed for open environment that consists of highways, so there is no need of junction selection mechanism or computation of anchor points as done by all position-based protocols considering city environment characteristics. The use of GPS and static maps are vital to get the position of vehicle. DGR assumes the presence of location service to find the position of destination. Furthermore, it also assumes that each vehicle knows its velocity and direction. Directional greedy forwarding approach is used as a forwarding strategy to forward packet towards destination. The formula for selecting a node which moves towards destination and is a closest node towards destination is given below:

$$w_i = \alpha(1 - D_i/D_c) + \beta \cos\left(\overrightarrow{V_i}, \overrightarrow{P_{i,d}}\right)$$

D_i is the smallest distance from node i to destination and D_c is the smallest distance from source to destination. $\overrightarrow{V_i}$ is the vector representing velocity of node i and other vector $\overrightarrow{P}_{i,d}$ representing the position of node i to destination. The first part of formula $(1 - D_i/D_c)$ represents a closeness of a vehicle towards destination whereas cosine values of two vectors represent moving direction of a vehicle. Here α and β are the weights with $\alpha + \beta = 1$. By adjusting the value of $\alpha = 1$ and $\beta = 0$, it becomes greedy forwarding routing protocol and by adjusting the value of $\alpha = 0$ and $\beta = 1$, it becomes directional forwarding but this will not select a node which is closest towards destination. In order to select a node, which is moving towards destination and is also closest node towards destination. We set $\alpha = 0.1$ and $\beta = 0.9$, this way it satisfies both the condition. By setting values $\alpha = 0$ and $\beta = 1$, it satisfies only one condition i.e., it selects vehicle in the particular direction, but not both. Thus, to select closest vehicle to destination, set $\alpha = 0.1$.

Predictive directional greedy routing (Gong et al., 2007) is an extended version of DGR which is based on the same assumption as DGR. Each vehicle not only broadcasts its geographic position but it also broadcasts the geographic position of its one hop neighbors. Predictive directional greedy strategy is used to relay the packets towards destination. The main disadvantage of PDGR is overhead in calculating and disseminating two-hop neighbors. DGR and PDGR both protocols are implemented in highway scenario and show significant performance improvement but they are yet to be tested in city scenario. They cannot be simply implemented in city environment as it is. In fact, some modification is needed to fit it in city environment.

Improved greedy traffic aware routing protocol GyTAR (Jerbi et al., 2007) is a geographic routing protocol works well in city environment. The most vital contribution of this paper is the dynamic junction selection mechanism. It consists of two parts, dynamic junction selection mechanism and forwarding strategy between two involved junctions. First, next junction is selected and then protocol implements forwarding strategy in selected junction. Source node finds the position of destination node via grid location service (GLS) (Li et al., 2000). Digital maps are used to identify the position of junctions and also to find shortest path towards destination via Dijkstra shortest path algorithm.

The junction selection mechanism is based on vehicular traffic and curvemetric distance to the destination. Vehicle computes next junction by considering curvemetric distance from each candidate junction to destination and also considers the vehicular density from itself to each candidate junction. Dynamic junction selection mechanism along with vehicular traffic makes GyTAR to find robust routes within the city. A distributed mechanism Infrastructure-Free Traffic Information System (IFTIS) (Jerbi et al., 2007) is used to compute vehicular traffic density between two junctions. Score is given to each junction on the basis of curvemetric distance to the destination and vehicular traffic density. The junction having highest score is selected as next destination junction.

As described in Section II, improved greedy forwarding is used to forward data packets between two involved junctions as shown in Fig. 7. When source vehicle reaches the intersection point, it has three options, forwards packet to junction *J1*, forwards packet to junction *J2* or forwards packet to junction *J3*. Source vehicle computes curvemetric distance from each candidate junction to destination (as shown in three different lines) and also considers vehicular traffic density from source vehicle to each candidate junction before selecting next junction. Source vehicle selects *J2* as next destination junction because street *J2* has enough connectivity and the curvemetric distance from *J2* to destination vehicle is less than any other candidate junctions (*J1* and *J3*). At the point of local maximum, carry and forward recovery strategy is used in which a node buffers the packet until another node enters in its communication range or node reaches the intermediate junction. GyTAR shows significant performance improvement but it also has some limitations (Ali and Bilal, 2009). During the junction selection mechanism, GyTAR does not consider direction of vehicles. Consideration of direction of the vehicle is vital in a sense that it identifies the streets having

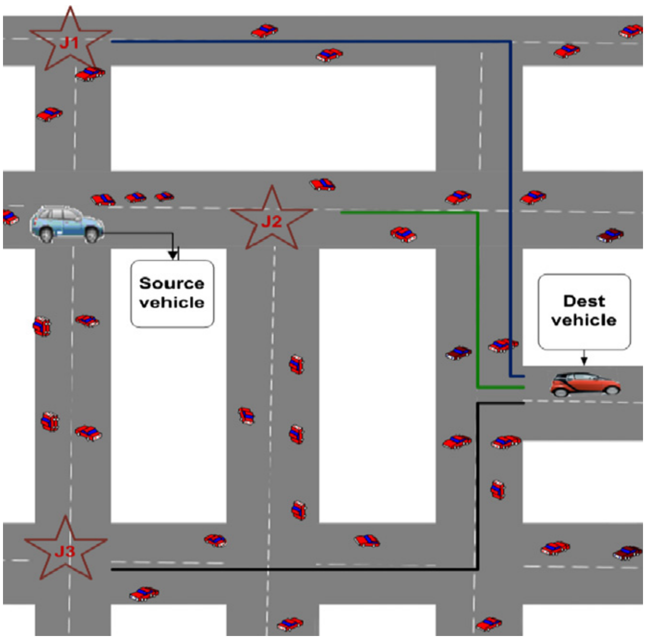

Fig. 7. GyTAR junction selection mechanism.

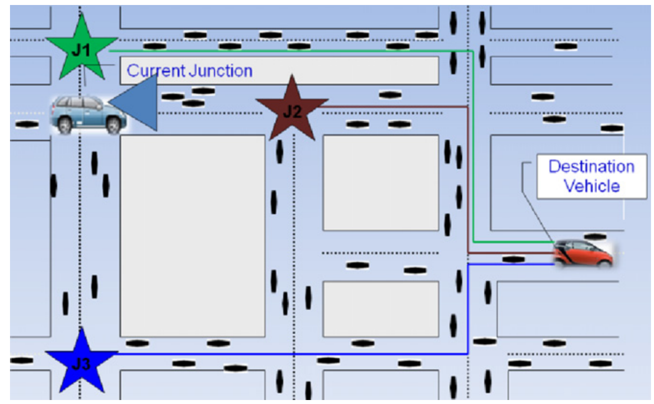

Fig. 8. Problem in GyTAR junction selection mechanism.

higher vehicular traffic in the direction of destination (Bilal et al., 2011). This also helps in avoiding local maximum problem, for instance, selecting a junction having higher vehicular traffic but all the vehicles moves away from the destination. In this case, packet travels towards current junction.

Enhanced GyTAR (E-GyTAR) (Bilal et al., 2011) is a modified version of GyTAR routing protocol which is designed for city environment. Like GyTAR, it is also based on same assumption of GPS device, digital maps, location service, and IFTIS mechanism. It selects junction dynamically but junction selection mechanism is different from GyTAR. In E-GyTAR, junction selection mechanism is based on vehicular traffic density in the direction of destination and curvemetric distance to the destination. It removes the limitation of GyTAR by considering the direction of vehicles before selecting the next junction. Score is assigned to each junction accordingly and junction having highest score is selected as next destination junction. Thus, selected junction has higher vehicular traffic moving in the direction of destination.

Fig. 8 illustrates this mechanism where E-GyTAR selects *J3* as a next destination junction while GyTAR selects *J2* as a next destination junction. By selecting *J2*, the GyTAR stuck in a local maximum problem, as all the vehicles moves towards source vehicle. In this way, E-GyTAR also avoids local maximum problem which occur when selecting streets having higher vehicular traffic but all the vehicles move away from the destination. Packets are forwarded by using improved greedy forwarding approach. Carry and forward recovery strategy is used to packets that stuck in local maximum problem. There are some issues in E-GyTAR as well, for instance, it preferred directional paths over non-directional paths, so with increased number of nodes, it misses non-directional paths which may provide shortest path having enough connectivity to route the packets towards destination. Packet may traverse longer paths to reach destination on unavailability of directional vehicular density. There are other position-based routing protocols (Lee et al., 2011; Mo et al., 2006) which are variant of E-GyTAR. They make the same assumption of location servers and digital maps and find the shortest path via Dijkstra algorithm. After the calculation of shortest path, MURU protocol (Mo et al., 2006) considers the quality of the route based on "expected disconnection degree (EDD)" parameter and then decides which path to select for data forwarding. The authors in (Oliveira et al., 2012) developed a path algorithm to increase the path duration and decrease end-to-end delay but they proposed their solution for non-position-based routing protocols. Recently, some work in the field of quality of services has also been done in V2V communication (Saleet et al., 2011). The protocols operable in city environments are non-directional routing protocols; they don't consider direction of vehicle while forwarding the packets. In literature, there are routing strategies which are directional and show significant performance improvement when applied to open environment (Gong et al., 2007). It is inspiring to implement directional routing strategies in city environment and compare it with state of art protocols of city environment. Routing protocols in city environment can be categorized into two categories on the basis of junction selection mechanism: Fixed and dynamic. Fixed junction selection mechanism is the one in which source computes sequence of junction at once and packet has to traverse computed sequence of junction in order to reach destination. On the other hand, in dynamic junction selection mechanism, junctions are computed dynamically, one after another, on the basis of metrics, i.e., number of vehicles on the street, distance towards destination, and number of vehicle moving towards destination on the street (directional density).

4. Vehicle-to-infrastructure routing

Vehicular ad hoc network improves performance to some extent but they suffer from network partitioning due to high mobility. Current research tends to combine both approaches (V2V, V2I) to get the desire result. Hybrid kind of network is much more efficient. This section explains few of position-based routing protocols which exploit both form of communication i.e., V2V and V2I. Vehicular networks are highly dynamic in nature and this dynamic nature of vehicles causes frequently topology changes affecting routing and packet delivery ratio. In addition, performance of vehicular routing protocols is also susceptible to the vehicular density. Vehicular routing protocols show significant performance variation under sparse and dense network. MDDV (Wu et al., 2004) and VADD (Zhao and Cao, 2008) perform well under dense network but show poor performance under sparse network due to frequently disconnected network. Static-node-assisted adaptive data dissemination in vehicular network (SADV) (Ding and Xiao, 2010) is designed for data dissemination in large scale network considering low vehicular traffic. SADV is a geographic-based routing protocol which deploy static node at intersection. In SADV, vehicular nodes forward packet to these static nodes on encountering local maximum problem. These static nodes then store the data packet and forward it when optimal path is available.

Fig. 9(a) illustrates this mechanism where shortest path to forward the packet is northward. When A forwards the packet towards B. B will try to forward the packet along the optimal path which is northward. As there are no other vehicles moving towards north, so B delivered the packet to static node. Static node buffers the packet until it finds a vehicle moving towards next optimal intersection. In Fig. 9(b), it forwards the packet to C. Static node cannot forward the packet to vehicle D, as it is not along the optimal path. Static node buffers the packet and after waiting for certain duration, it forwards to C which later moves in the direction of optimal path. Static nodes also compute the forwarding delay and propagate computed delay to adjacent static nodes. This helps in routing decision made at intersection. With the assistance of static node, SADV forwards the packet along optimal path; the path consists of minimum forwarding delay, and improves packet delivery ratio. SADV comprises of three parts; static-node assisted routing (SNAR), link delay update (LDU), and multipath data dissemination (MPDD). SADV assumes the presence of GPS in the vehicles and each node including static node periodically broadcasts beacon messages. Moreover, each static node is equipped with digital map containing street info.

In SNAR, packet is delivered towards the destination along the optimal path with the assistance of static nodes. Let us assume that static nodes are deployed at each intersection. Consider two adjacent intersection with static nodes S_i and S_j, respectively. S_t is the static node closest to destination vehicle *dst*. S_i will calculate the optimal path towards S_t based on delay matrix *d*. Ding and Xiao (2010) explains how to calculate the delay matrix *d*. After the computation of optimal path, S_i forwards the packet toward the next static node along the optimal path. Data forwarding in SNAR divided into three parts; in-road mode, static-node mode, and intersection mode. In in-road mode, if forwarding vehicle F has packet to send and is moving within the transmission range of static node, it will first send query to S_i regarding *dst* information. S_i computes the shortest optimal path towards destination static node S_t and replies with next intersection S_n in the path. Vehicle *F* selects the vehicle as a next hop which is moving towards S_n and is also closest vehicle towards S_n (directional greedy forwarding). If there is such a vehicle available, packet is forwarded to it. Otherwise, forwarding vehicle F forwards the packet towards S_i. When the packet is with static node S_i, it works as static-node mode. In this mode, S_i forwards it along optimal path when there are vehicles available until then it stores the packet in its buffer. Static node knows the position, velocity, and direction of vehicles by listening beacon messages. When forwarding vehicle F has a packet and it is not yet enters into transmission range of the static node, this is said to be vehicle operating in intersection mode. Suppose S_i is the next intersection, F forwards the packet to a vehicle which is closest to S_i (greedy forwarding). In order to compute the optimal path, real time link delay should be computed. SADV computes the real time delay by piggybacking the current time *stime* in data packet while forwarding packets from one static node S_i to other static node S_j. Whenever Si forwards the packet to S_j, it adds current time *stime* to data packet. On receiving data packet, S_j computes the delay by subtracting current time from *stime*.

$$d(s_i s_j) = etime - stime$$

The computed delay will be broadcasted to other nodes, so that they would have up-to-date information. These LDU consists of *srcId, destId, delay, seq,* and *expire. SrcId, destId* are starting and ending IDs of static node respectively, *delay* is the computed delay between static nodes *srcIdf* and *destId. Seq* is the sequence number used to indicate the most up-to-date message and *expire* identifies the time up-to which this information is valid. When these updates messages are received by adjacent static nodes, they will update their respective delay matrix. To limit the flooding, each static node only broadcast the newest LDU. Furthermore, each LDU is also limited by the number of TTL. Vehicular networks are highly dynamic network, so this paper uses the concept of multipath especially in a case where the payload is not very high. Packets are delivered to destination through multiple paths only at intersection. In each static node, packet is delivered through first and second best path computed via delay matrix. SADV is basically designed to improve the performance under low or median vehicular traffic density.

Infrastructure-assisted geo-routing (Borsetti and Gozalvez, 2010) is designed to take the advantage of fixed infrastructure, where RSUs are deployed to make vehicular communication more reliable and reduce the unwanted delay in different vehicular applications especially in safety applications. These RSUs are fixed and are connected to each other through higher bandwidth and reliable backbone network. Independent of geographic location of the RSUs, the data packets from RSU to other RSU will be sent by using this high bandwidth backbone network. Infrastructure-assisted geo-routing uses GSR routing protocol, which is basically designed for V2V communication, to analyze the potential advantage of V2I over V2V communication. The routing algorithm assumes the presence of digital maps, and location servers. It modifies the existing network graph of GSR by including RSUs. A node in a graph can be either anchor point or RSU.

Distance between two consecutive nodes (weight) is computed which allow a source vehicle to finds shortest path towards destination vehicle by using Dijkstra algorithm. All RSUs can be integrated into one unit called backbone gateway due to the fact that they are connected to backbone network. In case of GSR, the shortest path consists of node 3 and node 1 as shown in Fig. 10(a) but this is not the shortest path towards destination, as RSUs are interconnected though reliable backbone network and they can be considered as one unit. Hence, it is not optimal path. The optimal path would be through RSU-1 and RSU-2. Fig. 10(c) shows the advantage of fixed infrastructure where RSUs are combined into one node and source vehicle sends data packet

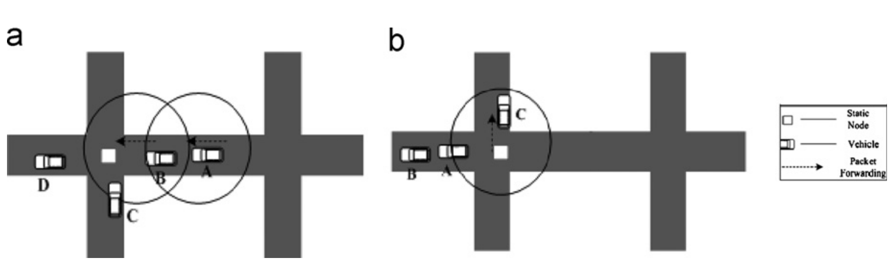

Fig. 9. Static node assisted routing.

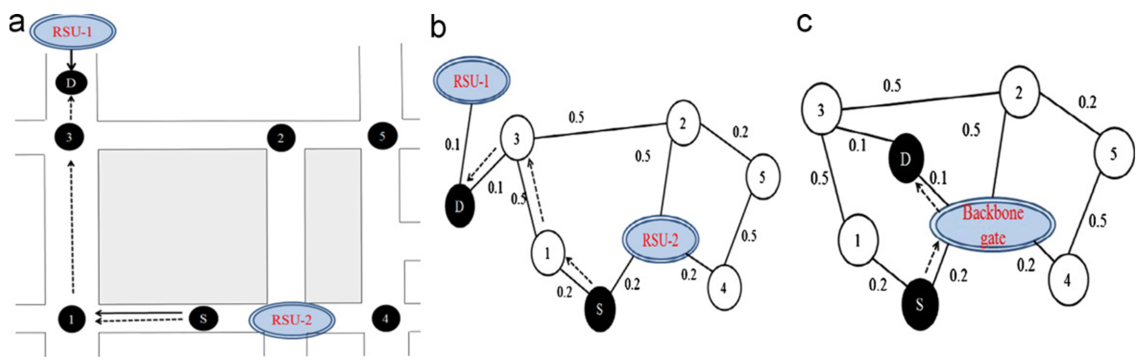

Fig. 10. (a). Path follow by GSR, (b) graph representation of GSR, (c) graph representation of infrastructure-assisted geo-routing.

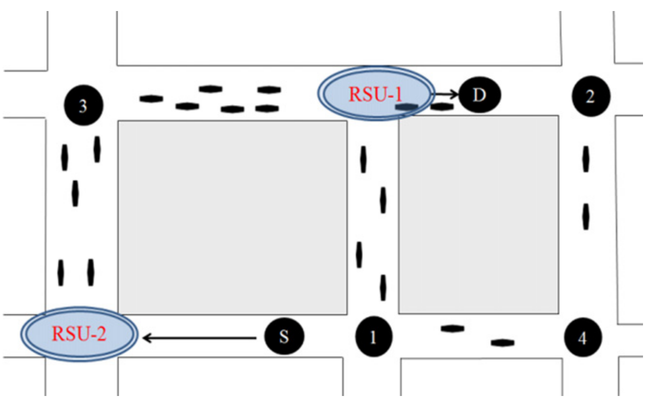

Fig. 11. Infrastructure-assisted geo-routing.

following the path through RSU-1 and RSU-2 which is the shortest path than traversing through node 3 and node 2.

Simulation results show (Borsetti and Gozalvez, 2010) that GSR would perform better by utilizing the fixed infrastructure, such as RSUs, and improve the multi-hop vehicular communication. One drawback of using fixed infrastructure is the number of RSU needed and placement of these RSUs in order to perform reliable multi-hop vehicular communication. Second, it may not be optimal to always forward the data packets towards RSUs. Fig. 11 shows a situation where forwarding packet towards RSUs may not be optimal. In this case, S has no other vehicle moving towards RSU-2, so S has to carry the packet until it reaches to RSU-2. On the other hand, it can decrease this delay if it considers the other path (1, RSU-1, D). This path will encounter less delay to deliver the packet to D than carry the packet to RSU-2. The proposed routing protocol could become more efficient by considering vehicular traffic density and direction of vehicles instead of just considering distance between two consecutive nodes.

Mobile infrastructure based VANET Routing protocol (Luo et al., 2010) is designed to overcome the restriction of fixed infrastructure or road side unit (RSU). Protocols like SADV (Ding and Xiao, 2010) utilizes static node as a RSUs. These static nodes are placed at road intersection in order to increase the packet delivery ratio by buffering the packets for a while until vehicle enters on the road segment along the best delivery path. These static nodes only act as data storage unit for a while but they do not take part in sending data packets from one static node to others. One of the drawbacks of using RSUs is the distribution and requirement of RSUs. In fact, the advantages of RSUs are restricted to the region where fixed infrastructure exists. MIBR exploits the concept of mobile gateway where RSUs are replaced with mobile vehicles acting as mobile gateways. The authors first observe the characteristics and features of urban vehicular networks and other factors affecting the vehicular communication and then finally propose MIBR based on their early findings. These observations include:

- Vehicular movement is constraint by the layout of the road and routing protocols.
- The movement patterns of vehicles are affected by the traffic rules and regulation, for instance, traffic speed and traffic light. In urban area, after passing traffic light, vehicles move in a particular direction in a form of cluster. Suppose the length of the road segment is L, speed at which vehicles move is V and duration of traffic light turns from red to green is T, then the distance between two cluster is $min\ (T \times V, L)$.
- Normally in urban area, there are two types of vehicles moving on the roads; cars and buses. The numbers of cars are much higher than the numbers of buses. According to (http://www.bjjtgl.gov.cn), only 20% of vehicles are buses in Beijing. Disconnectivity due to traffic speeds or traffic light can be overcome by increasing the transmission range of the buses which improve the connectivity of vehicular networks.

Above mentioned observations help the design of MIBR and shows the importance of buses and movement pattern of vehicles. MIBR assumes the presence of GPS, digital maps with bus line information and location services. Furthermore, it also assumes that each bus will have two interfaces; one for communicating with cars (R1) and other is to communicate with other buses on different channel R2 (R2 > R1). Buses form a mobile backbone to overcome frequent network disconnection. MIBR selects roads one after another by taking into account two factors; road condition and distance to destination. Forwarding vehicle selects a road which has minimum estimated hop count. Hop count can be estimated by considering number of buses in particular road segment. Therefore, the more the number of buses on the road segment, the higher will be the vehicular traffic density. If L_j represents the length of road segment j and X_i represents the total route length of bus i then number of buses N_j on road segment j will be:

$$N_j = \sum_i f_{i,j} * \frac{L_j}{X_i}$$

$$f_{i,j} = \begin{cases} 1 & \text{bus line } i \text{ contains road } j \\ 0 & \text{bus line } i \text{ doesn't contain road } j \end{cases}$$

Average distance between buses can also be computed as

$$\frac{L_j}{N_j}$$

After calculation of total hop count for certain route, distance to destination will be computed with minimum hop count and finally, MIBR selects road having less hop count and also closest to destination. Fig. 12 shows the selection mechanism of route where source vehicle S selects road segment one after another by considering both factors (hop count and distance to destination). Shadow road segment represents the selected segment. In a dense network (density of buses), packet will be forwarded from one road junction to other by using buses and in sparse network both vehicles, i.e., buses and cars, work together to carry out the forwarding process. Often, buses have higher priorities during forwarding phase of MIBR and thus, forwarding strategy is called "Bus First". In bus first strategy, forwarding vehicle first tries to select the bus as a next forwarder and if there is no bus available in neighbor table of forwarding vehicle then it selects car. Algorithm1 in Appendix A explains the bus first strategy where P is packet, F is forwarding vehicle and D is the constant number which is less than the range of both interfaces (R1 and R2). Simulation result shows significant performance improvement in term of packet delivery ratio and throughput when comparing to GPSR (Luo et al., 2010). Result also depicts the importance of bus first strategy over greedy forwarding strategy.

Mobile gateway routing protocol (Pan et al., 2011), a new position-based routing protocol which exploits both V2V and V2I communication to route packets, to increase the packet delivery ratio and decrease the average hop count. Fig. 13 shows the basic architecture of MGRP. MGRP is based on the concept of mobile gateways proposed in MIBR (Luo et al., 2010), which utilizes buses as a mobile gateway which has fixed routes but their connectivity is limited to the region covered by the buses routes and further by their scheduling time. But unlike MIBR, it makes use of vehicles such as taxi as a mobile gateway. IEEE 802.11 interface is used for V2V communication with nearby vehicles that do not have 3G interface or the vehicles which are not mobile gateways.

IEEE 802.11 interface is used for V2V communication with nearby vehicles that do not have 3G interface or the vehicles which are not mobile gateways. Upon receiving packets from IEEE 802.11 interface, mobile gateways forward the packet towards base station via 3G interface. Base station, in return forwards the packets to gateway controller. Gateway controller is responsible to finds the position of destination vehicle and forwards the packet to each of the mobile gateways which are closest to destination vehicle via base station. On receiving packet from gateway controller, mobile gateways forward the packet to destination vehicle by using IEEE 802.11 interface.

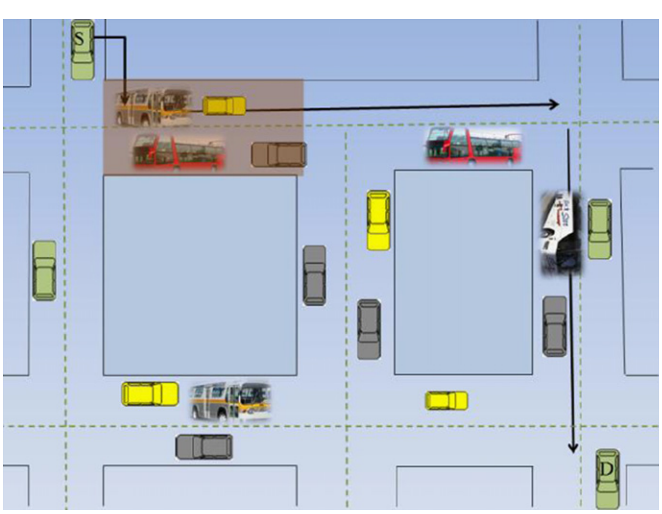

Fig. 12. Route selection in MIBR.

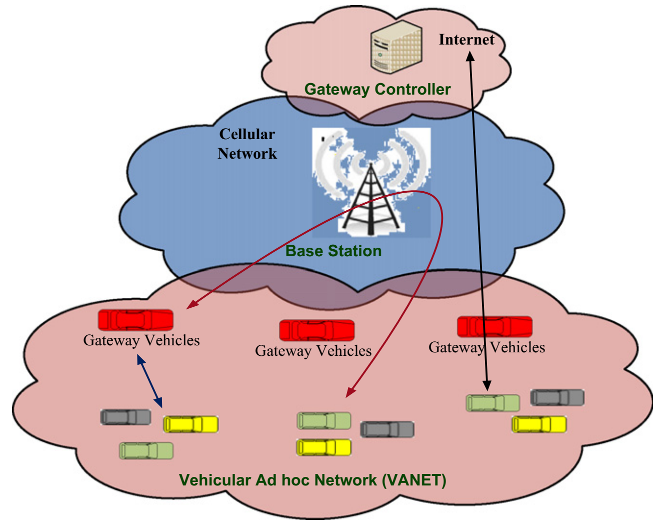

Fig. 13. Architecture of MGRP.

Like other position-based routing protocols, MGRP assumes the presence of global positioning system (GPS) and digital map so that each vehicle builds its neighbor table (including neighbor vehicles, directions and speeds) which would help in routing. Furthermore, digital maps provide traffic load condition of roads. The fixed RSUs are replaced with mobile gateways in order to provide connectivity in much larger region. Fixed RSUs only provide services where they exist; they don't provide service in an area where fixed RSUs are not deployed. This limits the benefit of V2I architecture to only those areas where RSUs are deployed. Mobile gateways equipped with two interfaces; IEEE 802.11(V2V communication) and 3G interfaces (V2I communication). Fig. 14 illustrates the complete routing mechanism of MGRP. Routing in MGRP consists of two phases; route request (RREQ), route reply (RREP) and data forwarding. If source vehicle has a path for the destination vehicle or mobile gateway then it simply forwards the packet. In that case, RREQ is not initiated by the source vehicle. If source vehicle does not have a path towards either destination vehicle or mobile gateway in its routing table then source vehicle broadcasts the RREQ packet to its neighbor vehicles with hop count equal to 3.

Upon receiving the RREQ packet, a vehicle looks for the value of hop count. If the value is equal to three, the packet will be dropped otherwise three different situations may occur. First, if source vehicle stuck in a local maximum problem, then source vehicle uses carry and forward strategy until another vehicle enters in its transmission range. Second, source vehicle (source 2) finds number of neighbor vehicles but the neighbor vehicles does not have the path towards destination vehicle or mobile gateway in three hops. In that case, source vehicle 2 selects vehicle 8 after considering vehicular traffic density of both road A & B. By considering road with higher vehicular traffic density will increase the probability of finding a mobile gateway. Lastly, if source vehicle finds more than one path towards mobile gateway, then source vehicle selects that route which is more reliable. Reliability is measured in term of link life time which is:

$$\text{Link-lifetime} = \frac{R - D_{k,j}}{V_k - V_j}$$

where R is the transmission range of vehicle, $D_{k,j}$ is the distance from vehicle k to vehicle j, V_k and V_j is the velocity of vehicle k and vehicle j, respectively. The smallest value of each link will be considered, for instance, in Fig. 14 the source vehicle selects a path comprises of source vehicle 1, vehicle 2, vehicle 3, and

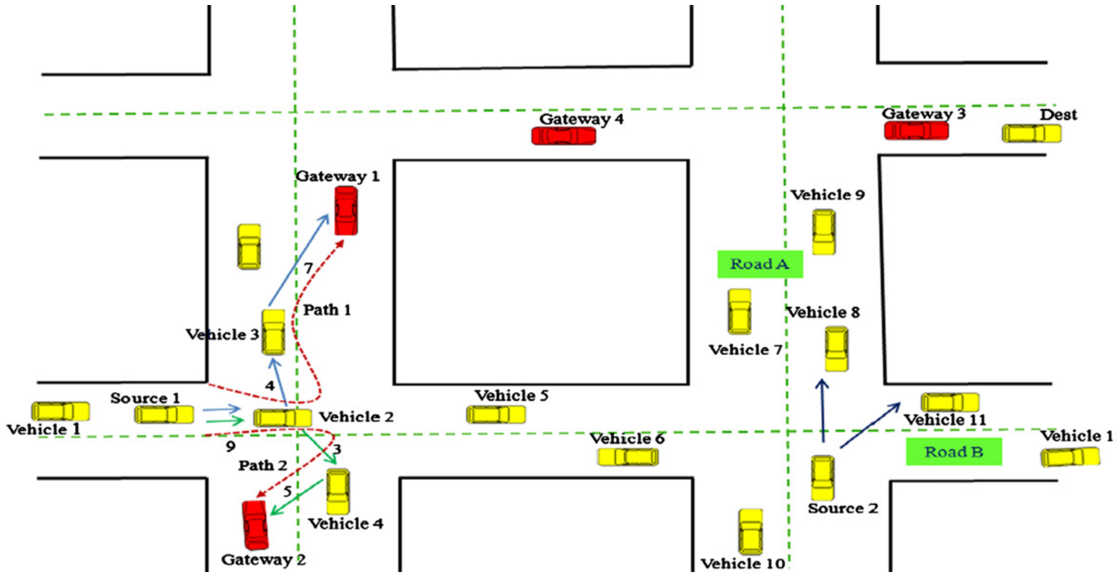

Fig. 14. Routing mechanism of MGRP.

Gateway 1, since this path has higher link life time i.e., the smallest value in both cases are 4 and 3, respectively for path 1 and path 2. If it finds a path towards destination vehicle, it will forward the packet towards that path without forwarding data packet to mobile gateway. If mobile gateway received data packets from source vehicle then it forwards the packet to gateway controller via base station by using its 3G interface.

Gateway controller finds the position of destination vehicle and selects all those mobile gateways which are closest to destination vehicle (within the range of 500 m). The gateway controller periodically updates the position of mobile gateway in order to find the closest vehicle near the destination vehicle. However, if the distance between closest mobile gateway and destination is greater than 500 m then gateway controller will drop the data packets. Simulation results proved that MGRP reduces the average hop count and increases the packet delivery ratio when comparing with GPSR (Pan et al., 2011). However, simulation result also shows the large routing overhead involved in MGRP due to maintenance of routing table which will reduce delay and increase packet delivery ratio. Furthermore GPSR is basically designed for mobile ad hoc network. It will be interesting to see the performance comparison of MGRP with traffic aware vehicular routing protocols like A-STAR, GyTAR, and EGyTAR. The performance of MGRP also restricted by the TTL values (equal to 3) especially in highly dynamic and disconnected network like vehicular networks.

5. Estimating real time vehicular traffic

Several of the above mentioned routing protocols are traffic aware; they know the real vehicular density but most of the traffic aware routing protocols do not describe how they get the real vehicular traffic. This section illustrates one such method. Estimating a real vehicular traffic density can be helpful in various applications, for instance, congestion warning system, to identify the routes with minimum delay and traffic efficiency.

Infrastructure-free traffic information system (IFTIS) (Jerbi et al., 2007) is one of the methods used to calculate the real vehicular density between adjacent junctions. In IFTIS, each road is divided into small cell of fixed size as shown in Fig. 15. The size of cell depends upon the transmission range of vehicles which is

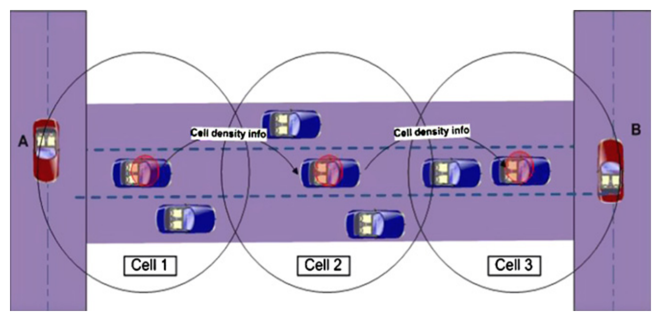

Fig. 15. Location-based groups.

usually around 250 m or in some cases 266 m (Jerbi et al., 2007; Bilal et al., 2011). The center of each cell is represented by small circle and a vehicle closest to cell's center is called group leader. Thus, each cell has one group leader which is responsible to calculate the vehicular traffic density of particular cell by calculating the number of neighbor vehicles in its neighbor table. Furthermore, group leader is responsible to forward the calculated traffic density of the cell to the group leader of the next cell in the form of cell density packet (CDP). Each group leader adds its own cell density and forwards CDP to next group leader and so on until it reaches to group leader of last cell. Last group leader calculates mean and variance of calculated density and broadcasts it around the junction. So, in this way, traffic density of the road will be calculated and this information will be available to vehicles, which employs different routing algorithms, to route the packets efficiently. For instance, GyTAR uses IFTIS technique to find the robust routes within the city, E-GyTAR modified IFTIS and make a distinction between directional and non directional vehicular traffic density which help in disseminating accident related information to specific side of the road. If accident happens on one side of the road then it should block one side of the road, not both sides of the road. The major drawback of IFTIS is the consideration of fixed cell size against each road. Each road has different length but IFTIS considers roads of length 500 m or multiple of 500 m (Jerbi et al., 2007; Bilal et al., 2011) which is impractical and unrealistic. IFTIS cannot provide accurately vehicular density information when different road lengths are considered. This is because during formulation of the cells, it only considers transmission range along with fixed road length. Thus, on different road length, sometime it does not fully cover the road segments and sometime it consider vehicular density of other road as well which result in a under calculated and over calculated vehicular density, respectively. According to IFTIS, if road length is represented by R and transmission range is represented by T, then total number of cells T_C is:

$$T_C = \lfloor R/(2 \times T) \rfloor + 1$$

Same formula has been used in hybrid traffic aware routing protocol (HTAR) (Lee et al., 2011) to compute the number of segments/cells. It is based on same mechanism as IFTIS but it maintains the computed density of each cell for routing purpose. As the road in IFTIS is dissected into fixed size cell, so the position of each cell's center will also be fixed (starting from 250 and then adding 500 each time to find position of center of specific cell). So, nth cell's center position will be:

$$P(n) = \sum_{n=1}^{\infty} (2 \times n \times T) - T$$

As IFTIS suffers from both under calculated and over calculated vehicular density, so all the decisions based on vehicular traffic density would be wrong which will result in degraded performance of routing protocols. To overcome such problem, a solution could be either to use V2I communication or develop distributed solution (V2V) based on dynamic transmission range by considering road factors such as road width and length. Calculating vehicular traffic is much easier task in V2I communication. One can assign different road to each RSUs and update the traffic status regularly before making forwarding decision. On the other hand, new V2V traffic estimating distributed algorithm can be developed based on the concept of dynamic transmission range by taking into account different road factors.

6. Discussion

Vehicular communication has seen tremendous transformation from V2V to V2I. Current trend is to develop routing protocol considering V2V and V2I communication capable of achieving maximum packet delivery ratio at minimum delay. Overhead generated by protocol has to be considered during protocol evaluation. V2V routing protocols, for example, GPSR and GSR perform well when comparing with MANET routing protocol but they show less packet delivery ratio due to the fact that they do not consider real traffic condition. Traffic aware routing protocols like A-STAR, GyTAR, and EGyTAR improves the packet delivery ratio and also minimize the end-to-end delay which is primary requirement for safety related application. GyTAR introduces the concept of dynamic junction selection mechanism, instead of calculating all the anchor points at once by source vehicle. This improves the performance and then finally in EGyTAR, directional of vehicle are also considered before selecting junction (dynamically) or the computation of anchors to further improve the performance. By considering all the traffic related factors, still VANETs are unable to deal with network partitioning. One solution is to deploy the access points along the road to make vehicular communication more reliable and reduce the unwanted delay in different vehicular applications. Unlike ad hoc and sensor networks, energy is not an issue because vehicles have rechargeable source of energy. So by deploying road side units alongside the road will increase the packet delivery ratio and also decreases the delay. SADV uses static node as RSUs but they act as data storage units and not take part in sending data packets from one static node to others.

Infrastructure-assisted geo-routing protocol connects these RSUs to each other and shaped into a high bandwidth backbone network. Packets are sent from one RSU to other RSUs via this high bandwidth backbone network. RSUs minimize the end-to-end delay to great extent but again the inherited problem of RSUs is how many of them are needed to cover the area and how much is the cost associated with each of them. Cost includes not only hardware cost but it includes installation cost, operational cost, and maintenance cost. Another issue with fixed infrastructure is that it provides coverage only those areas where the access points have been deployed. Those areas where access points are not installed are out of range, and hence information cannot be collected or provided. Mobile infrastructure-based VANET routing protocol overcome the restriction of fixed road side unit (RSUs). MIBR exploits the concept of mobile gateway where RSUs are replaced with mobile vehicles acting as mobile gateways. These mobile gateways operate on two different channels, one with much higher communication range than other interface. MIBR considers buses as a mobile gateway and these buses form a mobile backbone to overcome frequent network disconnection. The concept of buses are same as proposed in A-STAR but the problem with buses are that they have fixed routes and their connectivity is limited to the region covered by the buses routes. On the other hand if we consider other vehicles, such as taxi which do not have fixed route, as a mobile gateway, it will increase the coverage area. The mobile gateways (taxi) in MGRP equipped with IEEE 802.11 and 3G interfaces. Inter-vehicle communication is established via IEEE802.11 interface and 3G interface is used while communicating to base station. The problem with MGRP is that it drops the packets if gateway controller does not find a mobile gateway within the 500 m range of destination. MGRP and MIBR both are traffic aware routing protocols; they know the real traffic condition. Table 1 summarize the characteristics of position-based routing protocols.

7. Open issues in vehicular communication

In this paper we discussed different position-based routing protocols for both V2I and V2V communication. Currently, most of the research is focus to provide connectivity anywhere at any time in a seamless way based on multi-hop paradigm. Both V2V and V2I communication can be used simultaneously to achieve this object but there are some limitations which need to be addressed. As we explained number of position-based routing protocols for V2V communication, we observed that most of these routing protocols assume the presence of location server to find the position of destination vehicle (Lochert et al., 2003, 2005; Seet et al., 2004; Jerbi et al., 2007; Bilal et al., 2011). These location servers are usually designed for mobile ad hoc network and it cannot be implemented to VANETs without any modification. VAENTs are highly dynamic network and due to their dynamic nature, the topology of VANETs is frequently changed. Thus, we cannot implement MANETs location servers to VANETs. We also realized through comparative study that there is a need of efficient scheme for estimating vehicular traffic. Most of these routing protocols are traffic aware, they know the real vehicular density but most of the traffic aware routing protocols do not describe how they get the real vehicular traffic. We highlighted issues in section V and also provided solution to those issues. We are currently developing solution based on V2V communication by considering dynamic transmission range. Last but not the least, these routing protocols were simulated under ideal condition. They do n't consider effect of MAC layer on routing protocols. In addition, end-to-end connectivity is still a problem due to frequent disconnected network.

The major problem of disconnected network can be removed to some extent by considering V2I communication. Due to the use of infrastructure, cost factor should be considered; how many RSUs are needed to cover whole region. Through our comparative study we

Table 1
Comparison of routing protocols in V2I and V2V communication.

Protocols	Communication technology	Forwarding strategy	Anchor path computation	Traffic awareness	Simulation scenario
GPSR	V2V	Greedy forwarding	No anchor points computation needed	No	Highway
GSR	V2V	Greedy forwarding	Dijkstra algorithm with weight of hop count	No	Urban
A-STAR	V2V	Greedy forwarding	Dijkstra algorithm with weight of lines of buses	Yes	Urban
DGR	V2V	Directional greedy forwarding	No anchor points computation needed	No	Highway
PDGR	V2V	Predictive directional greedy forwarding	No anchor points computation needed	No	Highway
GyTAR	V2V	Improved greedy forwarding	Dijkstra algorithm with weight of traffic density and curvemetric distance	Yes	Urban
E-GyTAR	V2V	Improved greedy forwarding	Dijkstra algorithm with weight of directional traffic density and curvemetric distance	Yes	Urban
SADV	V2V and V2I	Directional greedy forwarding & greedy forwarding	Dijkstra shortest path (min forwarding delay)	No	Urban
Infrastructure-assisted geo-routing	V2V and V2I	Greedily forward to RSUs	Dijkstra algorithm with weight of hop count	No	Urban
MIBR	V2V and V2I	Greedily forward to buses	Dijkstra algorithm with weight of lines of buses shortest path (min hop count)	Yes	Urban
MGRP	V2V and V2I	Greedily forward to mobile gateway	No anchor points computation needed	Yes	Urban & highway

found that two different ways can be used to provide connectivity in a seamless way via V2I communication; fixed RSUs and mobile RSUs. Protocols based on fixed RSUs (Ding and Xiao, 2010; Borsetti and Gozalvez, 2010) can only provide the connectivity where they have been deployed. On the other hand, mobile RSUs overcome the restriction of fixed RSUs. The major limitation of V2I communication is the use of 3G to ensure the seamless connectivity. From one point of view, it is simplest approach without much complexity as 3G infrastructure is already deployed but from other point of view, 3G is already overloaded and suffering from high bandwidth (Gramaglia et al., 2011). The use of 3G connection, as in the case of MGRP (Pan et al., 2011), would increase the problem for mobile operators. This also demands the traffic load balancing techniques for WiFi and 3G connection. In addition, handover issues also need to be addressed in V2I communication. These are some of the issues which need to be addressed in future to provide connectivity anytime, anywhere.

8. Conclusion

This paper presents the detailed survey of routing protocols for inter-vehicle and vehicle-to-infrastructure communication. Initially, characteristics of vehicular ad hoc networks along with the forwarding strategies in the different protocols are described. There are mainly four types of forwarding strategies, out of which greedy forwarding (send the packet to the closest vehicle to the destination) is mostly used forwarding strategy. This paper highlights the different position-based routing protocols operable in city environment as well as in open environment along with their routing issues.

Generally, position-based routing perform better under high mobility. In past, different papers demonstrate the performance comparisons of position-based routing protocols for vehicular communication. This paper analyzed position-based routing protocols for V2V and V2I. Qualitative comparisons between numerous routing protocols (operable in city environment and open environment) have been presented. We discussed advantages and disadvantages of each of them in detail. We find that disconnected network is the major problem for V2V communication and this makes the way for vehicle-to-infrastructure communication but V2I is expensive (in term of cost) and also limited to the region where RSUs deployed. Again there is a tradeoff between using fixed infrastructure or mobile infrastructure. They are not compared with each other under the same simulation environment. In addition, the data overloaded problem of 3G make things worse especially in urban environment. Much of data overloaded problem is reduced thanks to Wi-Fi enabled device. This leads to develop a routing protocol which should be compatible with both communication modes in near future. Mobile gateway seems to be better solution than deploying fixed infrastructure. Later, we present traffic estimation technique which helps routing protocols to make forwarding decision based on vehicular traffic on the street. Furthermore, in future we are focusing to design a new routing protocol based on V2V and V2I communication along with mechanism for estimating real time vehicular traffic.

Acknowledgment

This work was supported in part by the European Union under the FP7 TREND (257740) and eCOUSIN (318398) Projects, the Spanish Ministry of Economy and Competitiveness under the eeCONTENT Project (TEC2011-29688-C02-02), the Regional Government of Madrid under the MEDIANET Project (S-2009/TIC-1468).

Appendix A

Algorithm 1 Pseudo code for Bus First Forwarding

```
If F has vehicles (bus or cars) on next road segment, then
  F forwards P to Bus on next road segment
else
  F forwards P to Car on next road segment
end if
If F is a bus and F has vehicles on next road segment, then
    If (distance between buses > D), then
        F forwards P to closest Bus to the next junction
    else
        F forwards P to Car
    end if
end if
If F is a Car and no vehicles on next road segment, then
  F forwards P to closest Bus to the next junction
else
    F forwards P to Car
end if
If F has no forwarding vehicles, then
    Drop the packet
end if
```

References

Ali S, Bilal SM. An intelligent routing protocol for VANETs in city environments. In: Proceedings of second IC4, 1-5, 17-18 Feb. 2009.

Bernsen J, Manivannan, D. Greedy routing protocols for vehicular ad hoc networks. In: Wireless communications and mobile computing conference, IWCMC '08. International, vol., no., pp. 632–637, 6–8 Aug. 2008.

Bilal SM, Madani SA, Khan IA. Enhanced junction selection mechanism for routing protocol in VANETs. The International Arab Journal of Information Technology (IAJIT) 2011;8(4):422–9.

Bilal SM, Saeed U, Mustafa S. Impact of directional density on GyTAR routing protocol for VANETs in city environments 14th international IEEE multitopic conference (INMIC), Dec 2011.

Bilstrup Katrin. A survey regarding wireless communication standards intended for a high-speed vehicle environment, Halmstad University (Technical Report; IDE0712), Sweden; Feb 2007.

Borsetti D, Gozalvez J., Infrastructure-assisted geo-routing for cooperative vehicular networks. In: Vehicular networking conference (VNC), 2010 IEEE, vol. no., pp. 255–262, 13–15 Dec. 2010.

Branscomb L, Keller J. Converging infrastructures: intelligent transportation and the national information infrastructure.Cambridge, MA: MIT Press; 1996.

Camp T, Boleng J. Wilcox L. Location information services in mobile ad hoc networks. In: Proceedingsof IEEE international conference oncCommunications ICC '02, pp. 298–3324, New York; April 2002.

Cha SH, Min-Woo Ryu MW, Cho KH. A survey of greedy routing protocols for vehicular ad hoc networks. Smart Computing Review 2012;2(2).

Cseh C. Architecture of the dedicated short-range communications (DSRC) protocol. In: Proceedings of. IEEE vehicular technology conference, VTC; 1998.

Ding Y, Xiao L. SADV: static-node-assisted adaptive datadissemination in vehicular networks. Vehicular Technology 2010;59(5):2445–55 Jun.

Festag A, Noecker G, Strassberger M, Lubke A, Bochow B, Torrent-Moreno, M. et al., Now—network on wheels: project objectives, technology and achievements. In: Proceedings of sixth international workshop on intelligent transportation (WIT), Hamburg, Germany; March 2008, 〈http://www.networkon-wheels.de〉.

Fogue M, Garrido P, Martinez FJ, Cano JC, Calafate CT, Manzoni P. Evaluating the impact of a novel message dissemination scheme for vehicular networks using real maps. Transportation Research Part C: Emerging Technologies0968-090X 2012;25:61–80, http://dx.doi.org/10.1016/j.trc.2012.04.017 December 2012.

Fonseca A, Vazão T. Applicability of position-based routing for VANET in highways and urban environment. Journal of Network and Computer Applications JNCA1084-8045 2009.

Fubler H, Mauve M, Hartenstein H, Kasemann M, Vollmer D. Location based routing for vehicular ad hoc networks. ACM SIGMOBILE Mobile Computing and Communications Review (MC2R) 2003;7(1):47–9.

Gong J, Xu CZ, Holle J. Predictive directional greedy routing in vehicular ad hoc networks. In: IEEE international conference on distributed computing systems workshops ICDCSW '07, vol. no., pp. 2, 22–29; 2007.

Gramaglia M, Bernardos CJ, María Calderón. M. Seamless internet 3G and opportunistic WLAN vehicular connectivity. EURASIP Journal of Wireless Communication and Networking 2011;2011:183.

IETF. The dynamic source routing protocol for mobile ad hoc network for IPv4," RFC 4728; Feb. 2007.

Jerbi M, Senouci SM, Meraihi R, Doudane YG. An infrastructure-free traffic information system for vehicular netwroks. In: Proceedings of 66th IEEE vehicular technology conference, pp. 2086–2090, 30 Sept–03 Oct 2007.

Jerb M, Senouci SM, Meraihi R, Doudane YG. An improved vehicular ad hoc routing protocol for city environments. In: Proceedings of IEEE international conference on communications, pp. 3972–3979, 24–28 June 2007.

Jiang D, Delgrossi L. IEEE 802.11p: towards an international standard for wireless access in vehicular environments. In: Proceedings of vehicular technology conference; 2008.

Karp B. Challenges in geographic routing: sparse networks, obstacles, and traffic provisioning Talk at DIMACS Workshop on Pervasive Networking, May 2001.

Karp B, Kung HT. GPSR: greedy perimeter stateless routing for wireless networks. ACM/IEEE MobiCom 2000.

Kakarla J, Sathya SS, Laxmiand GB, Ramesh BB. A survey on routing protocols and its issues in VANET. International Journal of Computer Applications 2011;28(4) 38–44 August.

Kargl F. Vehicular communications and VANETs, talks 23rd Chaos communication congress, Berlin, Germany; 2006.

Kiess W, Fubler H, Widmer J, Mauve M. Hierarchical location service for mobile ad-hoc networks. ACM SIGMOBILE Mobile Computing and Communications Review (MC2R) 2004;8(4):47–58 October.

Lee JW, Lo CC, Tang SP, Horng M, Kuo YH. A hybrid traffic geographic routing with cooperative traffic information collection scheme in VANET. In: Advanced communication technology (ICACT), 2011 13th international conference on, vol., no., pp.1496–1501, 13–16 Feb. 2011.

Lee KC, Lee U, Gerla M. Survey of routing protocols in vehicular ad hoc networks, Advances in vehicular ad-hoc networks: developments and challenges. IGI Global, 2010. 149–170. Web. 25 Sep. 2012. http://dx.doi.org/10.4018/978-1-61520-913-2.ch008.

Li J, Jannott J, Couto DD, Karger D, Morris R. A. scalable location service for geographic ad hoc routing. ACM/IEEE MOBICOM'2000 2000:120.130.

Liu G, Lee BS, Seet BC, Foh CH, Wong KJ, Lee KK. A routing strategy for metropolis vehicular communications. In: International conference on information networking (ICOIN), 2004. pp. 134–143.

Lochert C. Hartenstein H, Tian J. Fussler H., Hermann D., Mauve M. A routing strategy for vehicular ad hoc networks in city environments. In: Proceedings of IEEE on Intelligent Vehicles Symposium, 156-161, USA; 2003.

Lochert C, Mauve M, Fubler H, Hartenstein H. Geographic routing in city scenarios,. ACM SIGMOBILE Mobile Computing and Communications Review (MC2R) 2005;9(1):69–72.

Lochert C, Mauve M, Fusler H, Hartenstein H. Geographic routing in city scenarios. ACM SINGMOBILE Mobile Computing Communication Review 2005;9(1):69–72.

Luo J, Gu X, Zhao T, Yan W. A mobile infrastructure based VANET routing protocol in the urban environment. In: IEEE international conference on communications and mobile computing (CMC), Apr. 2010, pp. 432–37.

Mahlknecht S, Madani S. On architecture of low power wireless sensor networks for container tracking and monitoring applications, Proceedings Vol1, IEEE INDIN07, Vienna, Austria.

Mo Z, Zhu H, Makki K, Pissinou N. MURU: a multi-hop routing protocol for urban vehicular ad hoc networks. In: Third annual international conference on mobile and ubiquitous systems: networking & services, 2006, vol., no., pp. 1–8, July 2006.

Oliveira R, Luísa M, Furtadoa A, Bernardoa L, Dinisa R, Pintoa P. Improving path duration in high mobility vehicular ad hoc networks, ad hoc networks, Available online 18 May 2012, ISSN 1570-8705, Doi: 10.1016/j.adhoc.2012.04.009. 2012.

Pan H, Jan R, Jeng A, Chen C, Tseng H. Mobile-gateway routing for vehicular networks. IEEE VTSI APWCS 2011 August.

Perkins C, Royer E, Das S. Ad hoc on demand distance vector (AODV) routing. Internet Draft, IETF 2002.

Preetida V, Sanyal S. Routing protocols for mobile and vehicular ad-hoc networks: a comparative analysis *CoRR,* vol, abs/1206.1918, 2012.

Raw RS, Das S. Performance comparison of position-based routing protocols in V2V communication. International Journal of Engineering Science and Technology 2011.

Santos A, Edwards A, Edwards R, Seed L. Performance evaluation of routing protocols in vehicular ad hoc networks. The International Journal of Ad Hoc and Ubiquitous Computing 2005;1(1–2):80–91.

Saleet H, Langar R, Naik K, Boutaba R, Nayak A, Goel N. Intersection-based geographical routing protocol for VANETs: a proposal and analysis. IEEE Transactions on Vehicular Technology 2011;60(9):4560–74 Nov.

Seet BC, Liu G, Lee BS, Foh CH, Wong KJ, Lee KK. A-STAR: a mobile ad hoc routing strategy for metropolis vehicular communications. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications 2004:989–99.

Vehicle Safety Communications Consortium. (n.d.) Vehicle safety communications project: Task 3 final report: Identify intelligent vehicle safety applications enabled by DSRC; 2005.

Wai C, Guha RK, Taek JK, John L, YH. A survey and challenges in routing and data dissemination in vehicular ad-hoc networks. In: IEEE international conference on vehicular electronics and safety, ICVES 2008., vol., no., pp. 328–333, 22–24 Sept. 2008.

Wai C, Guha RK, Taek JK, Lee J, Hsu IY. A survey and challenges in routing and data dissemination in vehicular ad-hoc networks, In: IEEE international conference on vehicular electronics and safety. ICVES 2008, vol. no. pp. 328–33, 22–24 Sept. 2008.

Wang Y, Lin C, Hwang W, Tao C, Chou L. A practical routing protocol for vehicle formed mobile ad hoc networks on the roads. In: Proceedings of eigth IEEE international conference on intelligent transportation systems, 2005 pp. 161–165.

Wu H, Fujimoto R, Guensler R, Hunter M. MDDV: mobility centric data dissemination algorithm for vehicular networks. Proc.VANET 2004:47–56.

〈http://www.bjjtgl.gov.cn〉.

Zhao J, Cao G. VADD: vehicle-assisted data delivery in vehicular ad hoc networks,. IEEE Tranection on Vehicular Technology 2008;57(3):1910–22 May.

Zimmer MT. Personal information and the design of vehicle safety communication technologies: an application of privacy as contextual integrity. AAAS Science & Technology in Society 2005.