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Review

A systematic review on routing protocols for Vehicular Ad Hoc Networks

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ABSTRACT

Vehicular Ad Hoc Networks (VANETs) have emerged as a new powerful technology with an aim of providing safety for the persons sitting in the vehicles. Vehicles may be connected to the Internet with/without the existing infrastructure using various IEEE standards such as IEEE 802.11p. But as nodes in VANETs have very high mobility, so there are lots of challenges to route the packets to their final destination which need to be addressed by existing/proposing new solutions for the same. Keeping in view of the above, this paper provides a detailed description of various existing routing techniques in literature with an aim of selecting a particular strategy depending upon its applicability in a particular application. A detailed categorization of various routing techniques is provided in the paper with critical discussion on each categorization with respect to its advantages, disadvantages, various constraints and applications. Finally, numbers of parameters are selected for comparison and analysis of all the existing routing schemes in the literature.

1. Introduction

In recent years Vehicular Ad Hoc Networks (VANETs) have gained a lot of popularity due to its usage in number of applications like safety messages alerts in case of emergency, entertainment etc. Various government and private agencies have invested a lot of money in number of different projects in this area to improve safety and comfort of the passengers in the vehicle. In all these applications, messages are broadcasted from source to the destination for various effective operations [1,2].

The vehicles on the road communicate with each other either in Peer-to-Peer (P2P) manner or by using the existing infrastructure. In the former case, the communication is called as Vehicle-to-Vehicle (V2V) while in the later, it is called as Vehicles-to-Infrastructure (V2I). The infrastructure support is provided by the nearest Road Side Units (RSUs), which may act as an intelligent router to control all the activities of the vehicles on the road. If the vehicles are within the range of RSUs, then messages are forwarded to them directly else these are passed to nearest RSUs of the vehicles. But due to the high mobility and sparse distribution of the vehicles on the road, routing among the vehicles always remains a challenging task which may cause a long message delivery delay. The message delivery in VANETs follows store and forward strategy in which messages are kept at some of the intermediate nodes until the best forwarding nodes (Vehicles/RSUs) are found [3]. This process may have long delay due to this strategy. As VANETs are being used in wide areas of applications as discussed above, so such delay may affect the performance of many of these applications. Some standards are already being implemented in VANETs such as WAVE [4] and ETSI EN [5]. ETSI EN 302 636 gives direction how GeoNetworking, which is a network layer protocol, works for ad hoc networks especially in VANETs. It provides communication amongst vehicles without the need of any coordinating infrastructure. Vehicles specify the area where the message has to be transferred and intermediate nodes relay the message to vehicles in that particular area. For transmitting messages either of the three geographical routing schemes namely GeoUnicast, GeoBroadcast or Topologically scoped broadcast can be used. In GeoUnicast messages are unicast to vehicles in particular area. In GeoBroadcast the intermediate nodes unicast the messages until it reaches the desired area where the message is broadcasted to reach all vehicles in that area. In Topologically scoped broadcast message is broadcasted to all vehicles in n hop neighbourhood [5].

In order for communication amongst multichannel WAVE devices in mobile vehicular environment, the architecture and services must be used in conjunction with IEEE 1609 standards namely IEEE 1609.1-2006 Resource manager, IEEE Std 1609.2 Security services for applications and management messages, IEEE Std 1609.3 Networking services, IEEE Std 1609.4 Multichannel operation, IEEE Std 1609.5 Communication manager and IEEE 802.11p Amendment [4].

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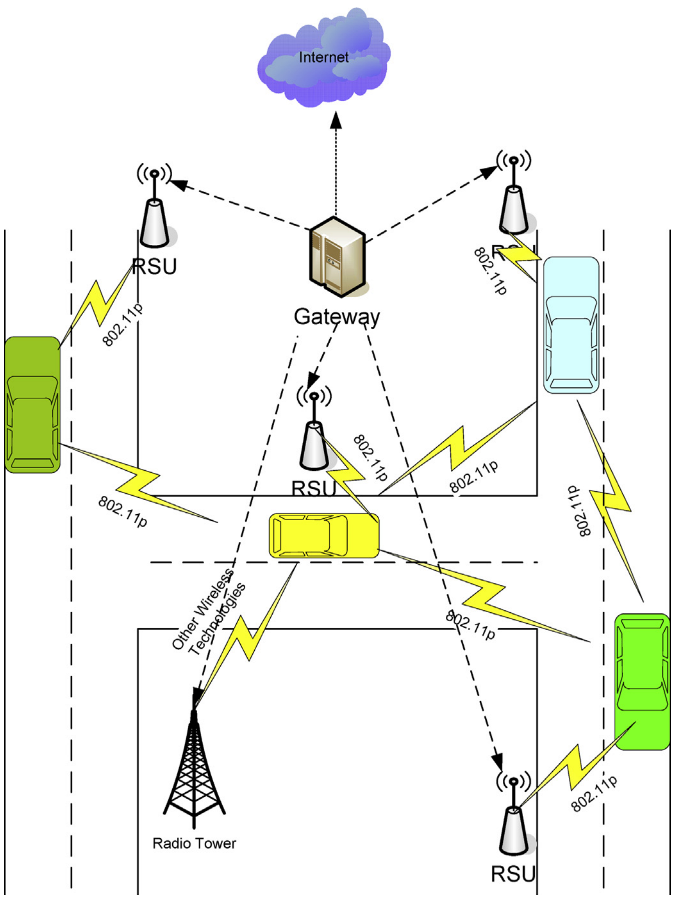

Fig. 1. Generalized architecture in VANETs.

1.1. Architecture and components of VANETs

For communication, vehicles may contain some units which can be used to establish the connection with other vehicles or to the infrastructure. Typically, following are the three most important components of VANET architecture: Application Units (AUs), On Board Units (OBUs) and RSUs. RSUs may act just like a router, which provides services to the moving clients [6] while OBUs and AUs are the consumer for those services. The communication among OBUs and AUs with RSUs can be done using wireless standards such as IEEE 802.11p.

The vehicles generally have OBUs installed on board of the vehicles, which can be used for providing communication among other OBUs or with RSUs. Moreover, OBUs also provide communication with AUs. OBUs are used for congestion control, IP mobility management, data collection and processing [6]. AUs are the sophisticated devices, which provide safety applications and communicate to RSUs by using OBUs. They may be separate units or may be integrated with OBUs as a single unit. RSUs are deployed as fixed units alongside the road in an optimized manner so as to preserve the coverage and connectivity to all the vehicles. They provide communication among the vehicles using Dedicated Short Range Communication (DSRC) or with the other RSUs and OBUs using IEEE 802.11p. Fig. 1 shows the various components of the generalized architecture used in VANETs.

Routing in VANET is dependent on number of factors such as velocity, density, direction of motion of the vehicles etc. As shown in Fig. 1, vehicles can be source or destination during the process of routing and various standards have been built to accomplish the task of routing.

With the growing needs of the users to access various resources during mobility, efficient techniques are required to support their needs from user satisfaction perspectives. The ultimate goals of routing in VANETs are to provide safety and comfort to the users sitting in the vehicles. Some of the applications where the necessity of routing is felt are: Generating alarms in case of emergency on the road/community, surveillance systems etc.

1.2. Applications of routing

The applications of routing can be broadly classified into three categories namely safety, transport efficiency and infotainment [6]. Fast message dissemination and collision avoidance can be categorized under safety application. Under transport efficiency, major applications are dynamic route scheduling and real time traffic monitoring. Other applications like asking for nearest gas filling station, seats available in a restaurant or movie timings in nearby movie hall which are not urgent but can improve comfort are categorized as infotainment application. Some more important applications of routing in VANET are:

Alert generations [6]

- RSU gathers, processes and analyses information of the vehicles moving towards intersection. Depending on the analysis if there is any possibility of collision/accident, RSU will generate alert and inform approaching vehicles and they will take proactive measures to avoid such situation.
- In case of emergency all the vehicles that are coming on vehicle's way are informed, so that they can give way to the emergency vehicles.
- Even in case when an accident has occurred, the vehicles approaching that area are informed so that they can take alternate paths.
- RSU are placed in specific areas like hospitals, schools, animal passing area etc. to send alert messages to vehicles approaching that area to slow down and not use horns.

Vehicle maintenance [6]

- Event Driven notification messages are sent to vehicles when the driver has set a reminder for recall or when there is a fault in the vehicle. In case of a fault the OBU sends a message to the infrastructure using V2I communication. The support centre replies back to the vehicle instructing the steps to be taken.

Community services [6]

- Co-operative downloading: A file is divided into pieces and these are available for download from the neighbours. The car selects the best peer for download. This cooperatively assembly of file is encouraged because of limited availability and capacity of access points. This cooperative downloading is possible through BitTorrent or CarTorrent [6].

Security services [6]

- Critical safety situations like major traffic congestion, weather condition, manmade or natural disaster or hostile attack can occur in any highway or urban environment. In such a situation, multimedia content like video can be streamed from one or more cars to the vehicles following behind so that they can be visually informed about the problem. These vehicles can make a better informed decision than if they simply got alarm text message.

1.3. Constraints and challenges

Due to the dynamic nature of VANETs, routing has various challenges and constraints with respect to management of Quality of Service (QoS) for various services:

- Constant topological changes due to high mobility of the nodes
- Varying density and velocity of the vehicles on the road
- Sparse distribution of vehicles in some geographical regions which leads to poor connectivity and performance degradation of the network
- Efficient clustering and selection of Cluster Head (CH) based upon some predefined criteria
- Intrusion detection and security

Based upon the above defined constraints and challenges, number of research proposals have been formulated in literature to address various problems in VANETs.

1.4. Taxonomy of routing in VANETs

There are different approaches to get an efficient routing protocol for reliable routing with high QoS parameters such as minimum End-to-End Delay (E2ED), security, low collision and interference. These are reviewed with respect to their achievements and limitations. The routing protocols for routing are classified into category based on following: Topology, Geography, Hybrid, Clustering, Opportunistic and Data fusion as shown in Fig. 2.

1.5. Organization

Rest of the paper is organized as follows. Section 2 describes Topology based routing in VANETs. Detailed discussion with comparative analysis is also provided in this section. Section 3 describes the Geographical based routing and also includes the comparative analysis. Section 4 illustrates about Hybrid routing techniques with their relative strengths and weaknesses. Section 5 highlights the Clustering based routing techniques. Section 6 discusses Data Fusion techniques. Section 7 gives analysis and comparison of all the discussed routing protocol techniques with respect to various parameters. Finally, Section 8 concludes the article and gives the future directions in this area.

2. Topology based routing

Topology based routing considers how the route is selected for sending the information from source to destination. So it can be classified as proactive and reactive based protocols used for routing and are described as follows.

2.1. Proactive routing schemes

Proactive schemes maintain fresh lists of destinations and their routes by periodically distributing routing tables throughout the network. Fig. 3 depicts classification of various Topology based schemes.

Namboodiri and Gao [7] proposed a Prediction-Based Routing (PBR) for VANETs. Vehicles on Wireless LAN (WLAN) use the vehicles that have both WLAN and Wireless WAN (WWAN) radios as mobile gateways to connect to the Internet while travelling on road. The main challenge to use such service is the frequent link breakages because of highly dynamic topology. While the vehicles on road have high velocity and change the direction rapidly still their motion is predictable. The authors proposed PBR and use this predicted routes to pre-emptively create new routes before the existing routes fail to minimize the failures. The authors have compared the proposed protocol with existing proactive and reactive protocols and found that the designed scheme is better than the other schemes. To minimize the ill effects of route length and mobility patterns, a high gateway density is recommended in this proposal. The simulation results prove that the PBR offers reduction in route failures and greatly improves Packet Delivery Ratio (PDR).

The overhead of checking and predicting routes is also very less and within tolerable limits. PBR which used predicted routes to pre-emptively create new routes before the existing routes fail and to minimize the failures. As the connectivity on the road is used for many applications, static gateways can be used to supplement mobile gateways. But lack of density on state highways and rural roads or the areas having low vehicle density, may cause connectivity problem that needs to be addressed for effective routing.

In Destination Sequence Distance Vector (DSDV) routing protocol proposed by Perkins et al. [8], two routing tables are maintained at each node namely routing table and setting time table. The routing table has the list of addresses of all other nodes in network. It also has the address of next hop, route metric, destination sequence number etc. The setting time, i.e., the time for update advertisement, for each destination is maintained in setting time table. Routes with later sequence number are selected. If sequence numbers are same, then the decision is made on smallest metric. DSDV ensures loop free routes. DSDV has some limitations as it has unidirectional link problem and it induces route fluctuation.

Toutouh et al. [9] proposed routing protocol for VANETs in which the optimization problem is defined with optimal parameter setting for Optimized Link State Routing (OLSR) by using an automatic optimization tool. OLSR is a routing protocol following proactive routing strategy which does periodic flooding of control information using special nodes that act as MultiPoint Relays (MPRs). In this scheme, the status of the links is immediately known which allow the hosts to know in advance the quality of network routes. There is an easy integration into existing operation systems and devices without changing the format of header of IP messages. OLSR is well suited for high density networks and is appropriate for networks with applications that require short transmission delays. Because of the capability of managing multiple interface addresses of the same host, VANET nodes can use different network interfaces and act gateways to other possible network interfaces and devices. The functionality of OLSR is performed mainly by three different types of messages: HELLO, Topology Control (TC) and Multiple Interface Declaration (MID). The authors study metaheuristic algorithms to find the automatically optimal configurations of the routing protocol. These algorithms are Particle Swarm Optimization (PSO), Differential Evolution (DE), Genetic Algorithm (GA) and Simulated Annealing (SA). The simulation results have following findings:

1. SA is best ranked algorithm, as it outperforms other algorithms in solving the defined optimization problem.
2. PSO offers the best tradeoff between performance and execution time requirements.
3. The use of optimized configurations reduces the routing load generated by OLSR.
4. It is proved from validation experiments that optimized configurations reduce the network workload.
5. PSO achieved the best tradeoff between QoS and routing overhead.
6. Automatically tuned OLSRs are more scalable than the standard version as they are less likely to be affected by medium access and congestion problems.

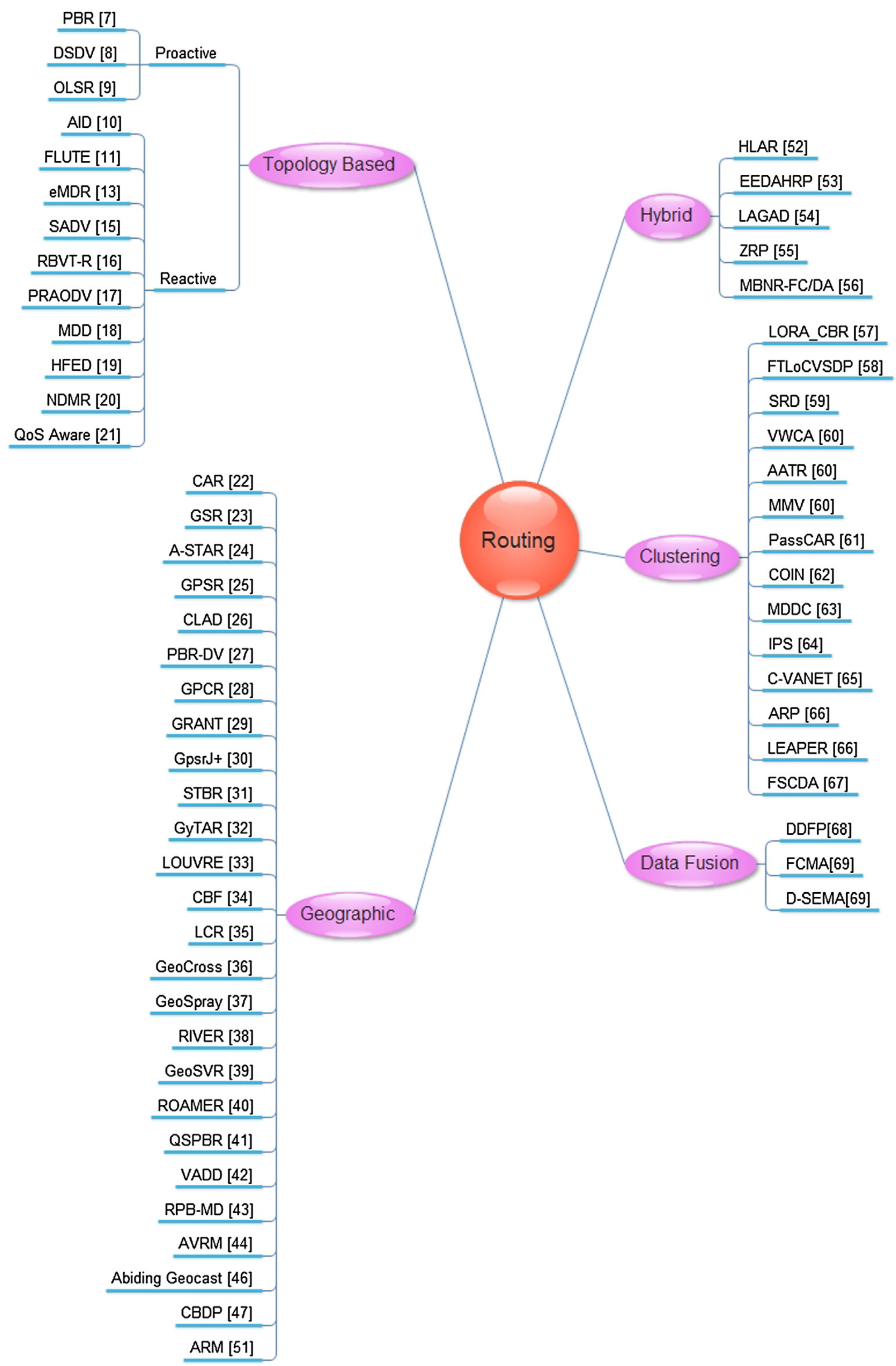

Fig. 2. Taxonomy of routing protocols in VANETs.

2.2. Reactive schemes

This type of protocol finds a route on demand by flooding the network with Route Request packets. They overcome the problem of heavy bandwidth consumption but it is slower than proactive routing where the link is available instantaneously. These protocols also have slower reaction for restructuring and failures. Following are the schemes in this category:

Bakhouya et al. [10] proposed adaptive Approach for Information Dissemination (AID) in VANETs. Each node takes help of local information gathered from neighbouring nodes. This information includes the number of neighbours and the distance between each other. By using this information, each node dynamically adjusts the value of local parameters. The proposed approach is evaluated with respect to various parameters such as Saved Rebroadcasts (SRB), awareness and latency. The results obtained show that AID is better than other conventional schemes of its category. The

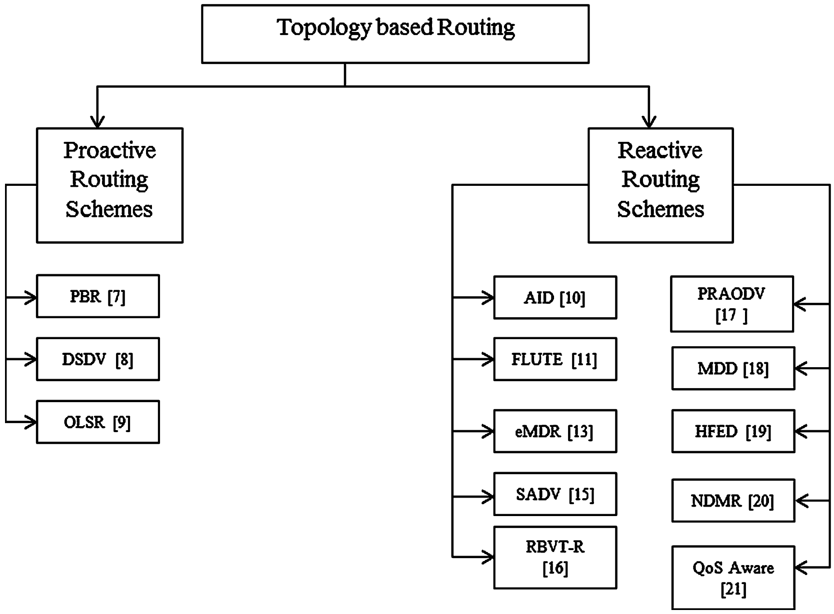

Fig. 3. Classification of Topology based schemes for routing.

authors have proposed a rebroadcasting algorithm that works as follows:

First time when a node receives a message, it initiates counters c and s. As the time passes the counter t goes down. If the message is heard again before counter expires, the counter c is incremented by 1. After the counter t expires, if counter c is less than or equal to zero then rebroadcast the message. If the message is heard again after counter t expires and threshold value (as explained below) is greater than zero then counter s is decremented by 1 and if the threshold value is less than or equal to zero the counter s is incremented by 1. The initial time is known as t_a and the time at which message is heard again is known as t_b. Threshold value is defined as [10]:

$$\frac{t}{c-(t_b-t_c)} \tag{1}$$

Calafate et al. [11] proposed an efficient and robust content delivery solution for IEEE 802.11p vehicular environments. In this proposal, the authors have proposed a robust content broadcasting system for the delivery of multimedia-based advertisement information to passing- by vehicles and people in urban environments. The optimal packet size value can be determined regardless of actual speed of the different vehicles. In order to make the content distribution more robust, reliable and fast, the system integrates the File Delivery over Unidirectional Transport (FLUTE). In the proposed FLUTE protocol broadcaster works as follows:

First the data file to be transmitted is opened in binary mode. After the creation of File Delivery Table (FDT), there is decomposition into source blocks then there is decomposition into encoding symbols of source symbols only with Forward Error Correction (FEC) [12]. After adding the redundancy through FEC, there is construction and transmission of FLUTE packets. At the receiver the reverse operation is carried out. As soon as the FDT is received, the related parameters are saved and incoming data packets are stored. After analysing the received packets, data encoding is done. When the data is fully received, it is handed to the application layer.

To maximize the throughput at the receiver, the following formula is used in which L_0 (the optimal packet size) is calculated as follows:

$$\theta(L_0).\delta(L_0,d_v) \geqslant \theta(L_i).\delta(L_i,d_v) \tag{2}$$

$$\forall L_0, L_i \in N\colon\ L_{\min} \leqslant L_i, L_0 \leqslant L_{\max}, L_0 \neq L_i \tag{3}$$

$\theta(L)$ is a function describing the maximum three layer load that can be input into wireless medium using IEEE 802.11p for a data gram of L bytes length. $\delta(L,d)$ is a function for the packet reception probability with parameters: distance (d) and packet size (L). d_v is the distance of vehicle from RSU and L_i is the packet size of all other packets that differ from optimal. $L_{\min}$ and $L_{\max}$ are minimum and maximum datagram sizes that can be encapsulated by a MAC layer frame. Simulation tests have been carried out in two different vehicular scenarios, static and dynamic and results show that Raptor FEC scheme gives the best performance.

Fogue et al. [13] proposed a novel message dissemination scheme for VANETs using real maps. The authors presented the enhanced Message Dissemination based on Roadmaps (eMDR) mainly to increase the percentage of informed vehicles and reduce the notification time. The protocol works successfully in urban scenarios where the density of vehicles is high and there are buildings which absorb radio waves making the communication only possible for vehicles in the line-of-sight. Vehicles operate in two modes, normal and warning. The default behaviour is normal mode but when vehicle detects a dangerous condition it starts working in warning mode. The authors proposed two algorithms for sending and receiving messages. In case of sending, if the vehicle is in warning mode then the message priority is set accordingly and the message is broadcasted. The gap between consecutive sending messages is also set accordingly. In case of receiving, if message is warning and if the distance between sender and receiver is greater than a threshold distance or both vehicles are in different streets then the message is rebroadcasted. If any of above four cases fails, the message is discarded. The simulations are performed and results are compared with existing protocols namely the location based scheme and distance based scheme [14]. It is shown that eMDR performs better than the compared protocols. The proposed protocol also mitigates the problem of broadcast storm which is common in urban scenarios.

Ding et al. [15] proposed SADV which depends on static nodes that are placed at intersections. Vehicle carries a packet when it has no messages to forward. The packet is forwarded to static node when the vehicle is within its range. The static node stores the packet and transmits it when the optimal path is available. These static nodes measure the delay of forwarding between each

Table 1
Relative comparison of Proactive routing schemes.

	No. of vehicles	PDR	Latency	Network load	Route length	Gateways	Control/routing overheads	Bandwidth usage	Route failure	Feasibility
PBR [7]	Medium	High	ND	ND	Low	Low	High	High	Medium	Medium
DSDV [8]	Medium	High	High	ND	ND	ND	Medium	ND	Low	Medium
OLSR [9]	Low	Medium	Medium	Medium	ND	ND	High	High	High	Low

ND = Not Determined.

Table 2
Relative comparison of Reactive routing schemes.

	No. of vehicles	PDR	Latency	Route length	Vehicle density	Warning notification time	Speed	Bandwidth consumed	Feasibility
AID [10]	High	Medium	Low	ND	Medium	ND	Medium	Medium	Low
FLUTE [11]	Medium	Medium	ND	ND	Low	Medium	Low	Low	Medium
eMDR [13]	High	High	Medium	ND	High	Medium	High	Low	High
SADV [15]	High	Low	High	Medium	High	ND	Medium	ND	Low
RBVT-R [16]	Medium	Medium	Low	High	Medium	ND	Medium	Medium	Medium
PRAODV & PRAODVM [17]	Medium	Low	ND	ND	Medium	High	Medium	Medium	Low
MDD [18]	Medium	ND	Low	High	Medium	ND	Medium	High	Medium
NDMR [20]	Medium	Medium	Medium	Low	Medium	ND	ND	Medium	Medium
QoS Aware [21]	Low	ND	Low	ND	Low	Low	Low	Low	Low

ND = Not Determined.

other to adapt to changing vehicle densities. In this protocol, multi-path routing mechanism is used to reduce the data delivery delay which in turn increases the overhead of the system. Nzounta et al. [16] proposed Road Based Vehicular Traffic Reactive (RBVT-R) routing protocol which combines geographic forwarding and route discovery. To discover a path to Destination D, Source S broadcasts a Route Request (RR) packet. Once D receives RR, it replies with Route Reply (RP) containing the connected path to S. When all the vehicles from S to D are connected, then there is no need of store and forward. But if there is a broken link, the intermediate vehicle V carries packet for a specific time λ.

Namboodiri et al. [17] proposed two prediction based AODV protocols namely PRAODV and PRAODVM. With AODV for VANETs the routes created breaks very frequently because of dynamic nature of mobility. The authors have used speed and location information of nodes to predict the life time of links. AODV chooses alternate route when there is a link failure but in PRAODV, the new route is constructed before the end of route's estimated lifetime. PRAODVM unlike AODV selects the shortest path with maximum predicted life time. Simulations show the slight improvement in PDR. The proposed method depends heavily on the accuracy of prediction method.

Liu et al. [18] proposed a bidirectional traffic model and studied that how the Message Delivery Delay (MDD) in VANETs is affected by two factors namely message delivery distance and density of vehicles. It is found that MDD is linearly dependent on message delivery distance, i.e., larger the distance, more will be the delay. As the density of vehicles and their velocity increases, the delivery delay decreases but there is an upper bound on this linear relationship.

Palomar et al. [19] have proposed Hindering False Event Dissemination (HFED) in VANETs with proof-of-work mechanism to address the problems like illusion, collusion and Sybil attack. Normally when any warning message is to be propagated by any vehicle there is no check and the sender might send wrong messages leading to confusion for the receiver. The authors have proposed a mechanism in which the sender sending Event Warning Messages (EVM) have to do some negligible computation. This computation cost is called Proof-Of-Work (POW) and is enough to discourage the dishonest vehicles from flooding the wrong message in the network. The POW imposed is dependent on following two factors:

- The capability of On Board Unit (OBU)
- The immediacy required for communication between the vehicles

The warning messages include a structure called Event Warning Certificate (EWC) which contains the event along with the non-repudiable proof attesting that the POW has been performed. The RSUs do the following tasks:

- They produce POWs and deploy them in case non-interactive POW scheme is deployed or produce on-demand POW in case interactive POW scheme is used.
- They store and transmit EWM and work on-line and off-line whenever EVMs are available.
- Collect evidence whenever any vehicle tries to threaten security and inform vehicles of their penalties in case any illegal action has been committed.

Huang et al. [20] examined the performance of Node-Disjoint Multipath Routing (NDMR). They also examined the effect of mutual interference on the behaviour of node-disjoint paths. Simulation results show that if there is careful path selection and node disjoint path, there is an improvement in terms of PDR and E2ED as compared to single path routing. Also there is improvement if both the paths are used to transfer packets. The energy efficiency of single path routing is higher than energy consumption of node-disjoint path routing without redundancy. If both paths are used, the energy consumption is more than single path routing.

Fathy et al. [21] proposed QoS Aware protocol for improving QoS in VANET. The protocol uses Multi-Protocol Label Switching (MPLS). MPLS runs over any layer two technologies and routers forward packets by looking at the label of the packet without searching in routing table for next hop. MPLS by using Traffic Engineering (TE) can determine the best route meeting the requirement of the packets but that route may not be the shortest. According to the proposed protocol, the vehicles send data through base station and wired infrastructure and create MPLS domain in wired domain. The protocol assumes that base stations are connected with wired network named Roadside Backbone Network (RBN). For wireless transfer, the protocol uses AODV. The simulations when compared with normal ad hoc protocol shows improvement in packet loss, throughput and E2ED.

Tables 1 and 2 provide the relative comparison of various topology based routing schemes. In this table Route length is total distance between source and destination. Latency is interval of time when first broadcast started to the time last host finished its broadcasting. Latency includes buffering, queueing, transmission and propagation delays.

2.3. Discussion

This section provides description of various Topology based routing approaches which are summarized in Tables 1 and 2.

In PBR, as the number of nodes increases, number of gateways required decreases due to multi hop capabilities of wireless ad hoc networks. Higher the density of gateways on the road, smaller will be the ill effect of randomness. PBR is better than other proactive protocols in terms of percentage of dropped packets because PBR is able to predict when the routes break and adjust its route creation interval accordingly, resulting in a decrease in the route failures probability. In PBR, larger node density improves connectivity but has no effect on route failures because it does not decrease route length [7]. DSDV fails to converge if vehicles don't pause for at least 300 s during movement. At higher rate of mobility in DSDV the PDR ranges from 70–92%. There is packet loss because of stale entries in network [8]. By using optimized configurations network load is reduced significantly and thus PDR of 100% is achieved in OLSR because of optimal parameter tuning of OLSR [9].

AID protocol gives best results if the speed is 25 m/s and number of nodes is up to 100 because the AID scheme increases the number of SRB hence congestion and latency is less [10]. Raptor FEC is more flexible and allows almost any recovery packet to contribute to the original message reconstruction and its file transfer time is very low [11]. But the average packet delay increases in almost all these scheme, as the number of vehicles increases to very high.

As the traffic density increases, mean buffer size decreases because when there are more vehicles around, there are more chances for the packets in buffer to be delivered [14]. eMDR performs better than other protocols as percentage of vehicles receiving the warning messages is highest and warning notification time is lowest. 95% of the vehicles received the warning message using eMDR [13]. In complex road map, reachability is lower as compared to where the streets are longer and mostly arranged in Manhattan Grid Style which favours the wireless signal propagation. So in later the percentage of vehicles receiving warning messages is high. RBVT-R has higher PDR than other schemes because of its integration of real time knowledge of vehicular traffic on roads [16].

There is a decrease in gateway connectivity with decrease in gateway density. Path lifetime increases with decrease in node and gateway density. On an average there is 80–85% gateway connectivity across different node densities [17]. The reason is that when node density decreases, there are fewer nodes in close proximity to connect and form fewer paths, hence lead to increase in path lifetime. As the node density increases, number of paths formed is more with some of paths forming between distant nodes, so more path breakages [17].

As the vehicle density increases, delay/distance ratio decreases because when the vehicle density is high, the probability of two successive vehicles being connected is also high which results in faster message delivery [18]. It has been proved that the delay/distance (s/m) decreases with an increase in the vehicle velocity. Message delivery delay is also linearly related to the message delivery distance in bidirectional traffic model [18].

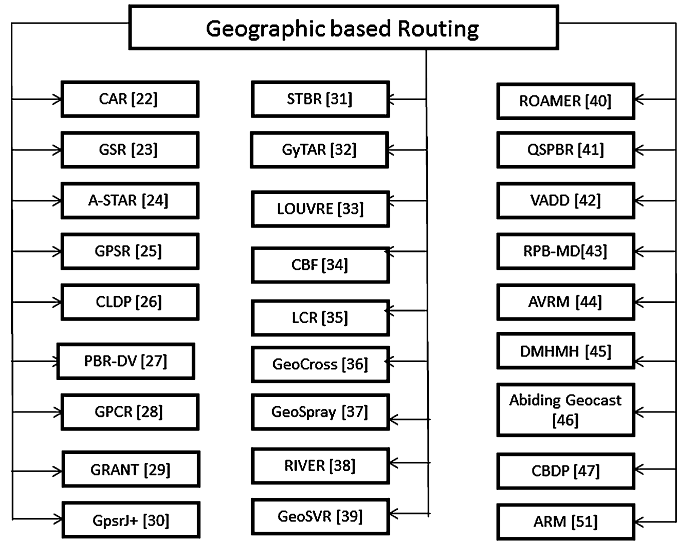

Fig. 4. Classification of Geographic based routing schemes in VANETs.

Error probability in E2ED increases as number of packets is increased from 1 to 100 [20]. A decrease in packet loss is observed by using MPLS as compared to AODV Ad hoc routing [21]. It is proved that packet loss is decreased by improving reception of data at destination and minimizing probability of link breakages [21].

For short distances, node disjoint paths achieve same performance as the single path because node disjoint paths don't diverge significantly from shortest path. For longer distances node disjoint paths improve the PDR compared to single paths [20].

3. Geographic routing

The Geographic routing based protocols rely mainly on the position information of the destination which is known either through GPS system or through periodic beacon messages. By knowing their own position and destination position, the messages can be routed directly without knowing the topology of network or prior route discovery. Fig. 4 shows various Geographic based routing schemes.

Naumov et al. [22] proposed Connectivity Aware Routing (CAR) in VANETs. CAR uses AODV based path discovery to find routes. It also used limited broadcast from Preferred Group Broadcast (PGB). Nodes that form the route do not record the previous node. They do not use the backward learning. Nodes near the crossing or a road curve are recorded in the path discovery packet. These nodes are called anchor points. A node determines itself as an anchor point if its velocity vector is not parallel to the velocity vector of previous node in the packet. From the various path discovery packets that destination receives, it chooses the path that provides better connectivity and lower delay. Advanced Greedy Forwarding (AGF) is used to forward the route reply back to the source through the recorded anchor points. On receiving the route reply, source records the path to the destination and starts transmitting. Following greedy manner, the data packets are forwarded towards the destination through the set of anchor points using AGF. For handling the mobility of destination, CAR uses guards to track the current position of the destination. Guarding node redirects packets or adds information to the packets to eventually deliver the information to the packet's destination. Simulations have been done and CAR is compared to GPSR and GPSR + AGF. Results indicate that CAR has higher PDR than others because CAR guarantees to find the shortest connected path. CAR's path discovery overhead is checked by PGB. There are some overheads of storing guards but that is not in the data packets but in the beacons. The beacon overhead is not very high as findings show that on an average node broadcasts 2–3 guards during the simulation.

Lochert et al. [23] proposed a routing strategy for VANETs in city environments called as Geographic Source Routing (GSR) which uses Reaction Location Service (RLS) to get the destination position. The protocol uses street map to get the city topology. By using the Dijkastra's shortest path algorithm, the sender determines the junctions that have to be determined by the packet. Forwarding between junctions is done in position based manner. GSR provides promising routing strategy by combining geographic routing and topological knowledge from street maps. When compared with DSR and AODV, simulation results show that GSR has better average delivery rate, has smaller total bandwidth consumption and has similar latency of first delivered packet. GSR is only applied in city scenario and not in highways.

Liu et al. [24] proposed a routing strategy for metropolis vehicular communications. In this scheme, the authors propose a position based routing technique called as Anchor-based Street and Traffic Aware Routing (A-STAR). A-STAR computes the sequence of anchors or junctions by using street maps. Through these anchors, packet passes to reach the destination. These anchor paths are computed with traffic awareness. To identify an anchor path with high connectivity for packet delivery, A-STAR uses statistically related or dynamically related maps. Statistically related maps are used to find the city bus routes while dynamically related maps are used for monitoring the latest traffic condition. Both types of maps are used to find the best anchor paths. Local recovery strategy is used for local packets routed to local minimum. This strategy is more suited for city environment. In order to save the packet from being completely lost in the local recovery state the packet is traversed to new anchor path. In case that other packets are not lost in void area, the street at which local minimum occurred is marked temporarily as "out of service". Out of service streets are functional only after the time out duration and before that these streets are not used for anchor computation or re-computation. Simulation results show that A-STAR works better than GSR and GPSR with 40% more packets delivery.

Karp and Kung [25] proposed Greedy Perimeter Stateless Routing (GPSR) and Füßler et al. [34] proposed Contention Based Forwarding (CBF), for wireless networks where the node forwards the packet to the other node which is geographically closer to the destination. While forwarding, the node may reach the situation where its distance to the destination is closer than its neighbours distance to the destination. This is the state of local maximum. In such cases, GPSR recovers using perimeter mode which is based on right-hand rule. The right-hand rule works as follows:

When node P (say) gets stuck at local maximum, it chooses the node Q which is in counter clock wise direction to line joining P and destination D. The next hop Z is also in counter clock wise direction to the edge joining node Q and node P. If edge PD and QS intersects, the next node R is chosen to be counter clock wise direction to QS. The drawback to this protocol is that if the graph is not planar, i.e., when there are cross-edges in the graph then routing loops may occur.

CBF is compared with GPSR in highway conditions. With perimeter mode disabled and beacon interval of 0.25 s, PDR of CBF is higher. As the beacon interval increases the PDR of GPSR drops even further.

To overcome this issue, Kim et al. [26] proposed Cross Link Detection Protocol (CLDP) in which each node recursively and repeatedly probe its adjacent links to check if it has been crossed by other links. The probe follows the right-hand rule in GPSR as mentioned before but with additional feature of recording the links that cross the currently probed link. When the probe returns to the original node, the node decides which of the cross links is to be removed to avoid partitioning the network. It notifies the affected nodes that such cross link is unroutable and future packets will not consider the link for forwarding. CLDP has disadvantage of having high complexity, low scalability and its convergence time is very high. For 200 node wireless network, most links in concurrent CLDP converges within 15–20 probes; each probe's frequency is 15 s. The convergence time is 4 minutes which is not suitable for VANETs where the mobility is very high and topology keeps changing constantly.

The problem of local maximum is dealt differently in different protocols. In Position Based Routing with Distance Vector Recovery (PBR-DV) [27], the node which can't find any node nearer to destination, broadcasts a request packet by flooding giving its location and location of the destination. A node receiving the request checks if it closer to the destination than the transmitting node. If not, the receiving node records the location of sender and further floods the message with its location and location of destination. When a node finds itself closer to the destination, it keeps on traversing backwards until it reaches the initiator node which faced local maximum. The drawback of this protocol is that it requires flooding which consumes higher bandwidth. The authors have not done any comparison with other protocols so nothing can be said about its performance.

Lochert et al. [28] in their study found that urban street map forms planar graph. They proposed GPCR which uses both greedy and perimeter mode to forward a packet. The routing performance is improved because packets travel shorter hops in perimeter mode as shown in Fig. 5. Vehicle A forwards packets to vehicle B although vehicle C is in range because B is at junction. The node stops at junction where decision about turn is to be made. To know whether the node is at junction two strategies are proposed. In the first, nodes exchange beacon messages and if the node x has two neighbours y and z, which are in transmitting range of each other but both don't list each other as neighbours. This means that vehicle y and vehicle z are separated by obstruction which concludes that node x is at junction. The second strategy uses correlation coefficient that relates neighbour to the node. If the coefficient is 0, it signifies that there is no relationship between position of the neighbours and the node is at junction. Simulation results show an improvement in PDR in GPCR over GPSR.

Schnaufer and Effelsberg [29] proposed Greedy Routing with Abstract Neighbor Table (GRANT) in which each node maintains the data of next x hop neighbours. For selecting the next hop neighbour N, each node S computes metric containing the multiplication of distance between N and S, the distance between N and Destination D, and the change per hop for multi hop neighbours. The node N offering minimum metric is chosen the next hop neighbour. GRANT separates plane into areas so that there is only one neighbour per area. As the current node receives a beacon, it computes the broadcasting node, the neighbour node into respective areas and categorizes into different hops. The propagation model used takes into account the buildings that absorb the radio waves. Simulation results prove that the path lengths of most of the routes in GRANT are shorter than the path lengths by traditional greedy routing. Also in traditional greedy routing, the number of times the packet is recovered per route is higher than GRANT. In simulation the x hop neighbours were assumed to be available which is not always possible. There are large beacon overheads and inaccuracy in calculations which were not taken into consideration.

Lee et al. [30] proposed GpsrJ+ which is an improvement of GPCR. To predict which route the junction node will take, GpsrJ+ uses two hop neighbour beaconing. If it is predicted that at junction different direction will be taken then the packet is forwarded to junction node otherwise packet is forwarded to furthest neigh-

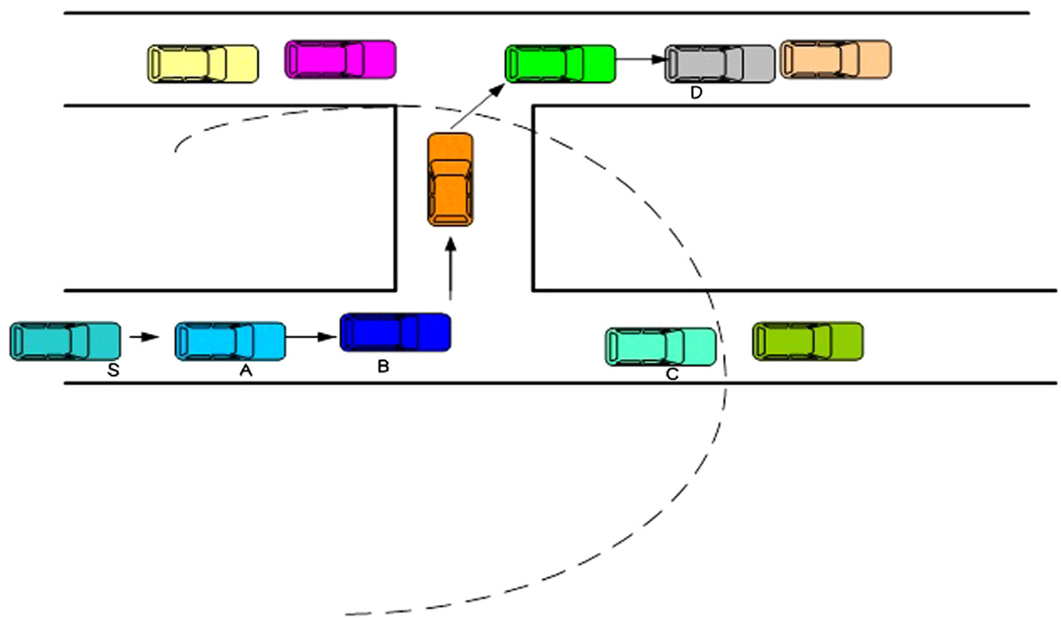

Fig. 5. GPCR routing along junctions [28].

bouring node. Simulation results show an improvement in PDR compared to GPCR.

Forderer et al. [31] proposed Street Topology Based Routing (STBR) which checks in which street destination is located and packets are routed based on their geographic distance to that street. In STBR to check if the links at next junction are up or not, one of the nodes at junction is selected as master. Every master receives every other master's link information. Every master's broadcast contains link information to all neighbouring links.

Greedy Traffic Aware Routing (GyTAR) proposed by Jerbi et al. [32] which determines the connectivity of roads by assuming that RSUs give the number of vehicles per road. Best junction is selected on greedy basis and packets are forwarded to that junction. GyTAR takes into account the road connectivity and uses shortest path routing. GyTAR shows an improvement in PDR as compared to GSR but it is not compared to any other protocol of its category.

In Landmark Overlays for Urban Vehicular Routing Environment (LOUVRE) proposed by Lee et al. [33], the sequence of overlaid nodes is determined a-priori. Regardless of vehicular distribution, when the vehicular density is above threshold, the overlay link remains connected. Most routes use the same overlay links. It reduces delay for establishing overlay routes and global route optimality is also guaranteed. The road density and road connectivity is determined in peer to peer fashion. Density of all the connected roads is known. With road density above threshold Dijkastra shortest path road is built. Since LOUVRE has global knowledge of density distribution, simulations on VanetMobiSim performs better than GPSR and GPCR. Also LOUVRE rarely encounters local maxima, hence does not use recovery mode. Because of this its hop count and delay is also very less. But the drawback of this protocol is that it is not scalable.

Kim et al. [35] proposed Lazy Crosslink Removal (LCR) which reduced message complexity by only removing the loop-inducing the cross links. When LCR detects that a looped walk does not contain a cross-link, LCR initiates a recursive search on the adjacent faces for cross link. LCR has higher PDR than CLDP but the cost of probing messages for improvement grows with increasing level of recursion and the number of nodes in the network. This overhead is even higher for nodes in VANETs which are highly mobile.

Lee et al. [36] proposed GeoCross that utilizes the street maps which are naturally planar graphs. GeoCross uses three fields, Probe, Unroutable Roads (UR) and Visited Faces (VF). Probe records the roads and junctions that the packet has travelled. UR records the road segments that are unroutable. GeoCross works as follows:

When a node receives packets forwarded in perimeter mode, it first checks for loops by looking at the probe field. If it finds the loops, next it checks for cross links. It removes the detected cross links and forwards the packets according to the loop. If the loop has adjacent cross link, the node determines the cross link to be removed and records it in UR field. Future forwarding nodes look at the UR field and forward to the nodes accordingly. If there are multiple cross links in the loop, the cross links are removed one by one as the packets looping back to the same node. GeoCross is made complete by using recursive traversal similar to LCR but it has far too many overheads. GeoCross is compared with GPSR and GPCR and its PDR is found consistently higher than others.

Soares et al. [37] proposed GeoSpray routing protocol which combines store-carry-and-forward technique with routing decisions based on geographic location. These geographic locations are provided by GPS devices. In GeoSpray, authors proposed a hybrid approach making use of multiple copy and single copy routing scheme. In order to exploit the alternate paths, GeoSpray starts with multiple copy scheme which spreads a limited number of bundle copies. Afterwards it switches to single copy scheme which takes advantage of additional opportunities. It improves delivery success and reduces delivery delay. The protocol applies active receipts to clear the delivered bundles across the network nodes. Simulations were performed on the following parameters: delivery probability, average delivery delay, number of initiated bundles transmissions, number of dropped bundles and overhead ratio. Comparing with other geographic location-based scheme, single-copy and non-location based multiple copy routing protocols, it was found out that GeoSpray improves delivery probability and reduces delivery delay. This protocol has lower rate of dropped bundles and lower overhead ratio as compared to other protocols.

Bernsen and Manivannan [38] proposed Reliable Inter-VEhicle Routing (RIVER) which utilizes undirected graph representing the street layout. In this graph, the vertices are the curves or intersections in the streets and edges are street segments. Xiang et al. [39] proposed Geographic Stateless VANET Routing (GeoSVR). The authors claimed to address all the problems in geographic routing namely Local maximum problem in which the relay node can-

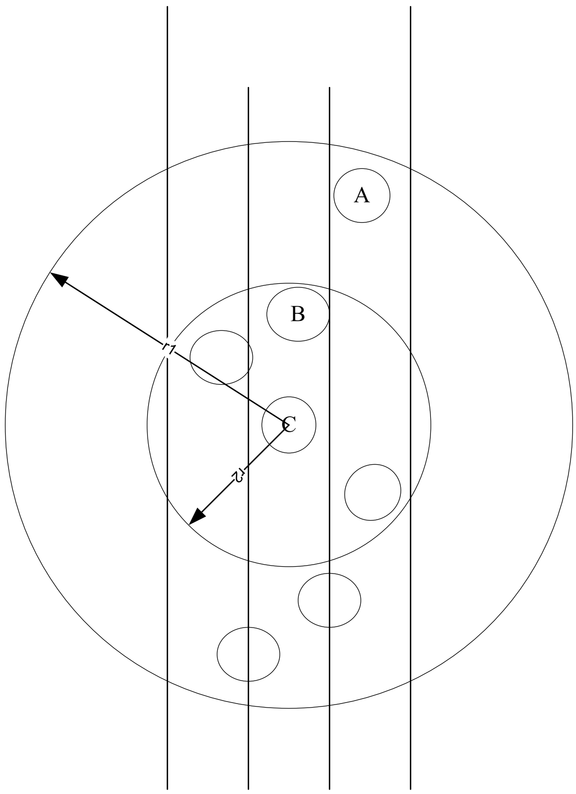

Fig. 6. Restricted Forwarding Algorithm [39].

not find any neighbour closer to the destination than itself, the Sparse connectivity which occurs when forwarding path to destination calculated by using maps but low vehicle density leads to packet dropping and the unreliable wireless channel in which the relay node runs out of communication range because of excessive distance between the two relays which leads to communication breakdown. For elimination of these three problems, authors proposed two algorithms in GeoSVR namely optimal forwarding path algorithm and restricted forwarding algorithm. The authors described the definition of optimal forwarding path as the shortest connected path with the highest probability of having the most vehicles between the source and destination. According to the algorithm the optimal forwarding path is calculated based on the location of the source and digital map by providing a global directive. The algorithm also considered the vehicle density on every road thus avoids local maximum problem and sparse connectivity. The map is used as weighted graph and Dijkastra algorithm is used to find the shortest path with minimum weight as optimal forwarding path. In the restricted forwarding algorithm, a neighbour is chosen for forwarding packets. As shown in Fig. 6 restricted forwarding algorithm finds the next-hop closer to r2, in order to reduce the interference of an unreliable wireless channel.

Free Space Path Loss (FSPL) in dB is calculated [39] as:

$$FSPL = 20\lg d + 20\lg f + 118 \tag{4}$$

where d is communication distance in meters and f is frequency in Hz

$$d = \frac{10^{\frac{FSPL}{20} - 5.9}}{f} \tag{5}$$

By using this proposed algorithm, the number of hops is increased but the results are positive in PDR and latency. Authors compared GeoSVR with AODV and GPSR considering urban and mobile scenarios. The results show that in GeoSVR and GPSR, the latency is less than 0.1 s while it is as high as 1 s in AODV. Despite of increase in the number of hops, there is reduction in latency and improvement in PDR proving that GeoSVR is better than other compared protocols.

Mershad et al. [40] proposed ROAdside unit MEssage Routers in VANETs (ROAMER), which can efficiently route the packets to distant locations. The authors proposed three algorithms. First algorithm is for sending a packet from vehicle to nearest RSU which searches for RSU in range. If there is no router in range, then it passes the packet to that vehicle which is nearest to the RSU. Second algorithm is for sending packet from RSU to a vehicle which determines the location of the destination vehicle. When it receives the packet, calculates the region in radius around the destination, finds the best road and sends the packet to all the vehicles in that radius. If the vehicle is outside the estimated area, it will search the packet within the estimated area (circle around the calculated radius). If no such packet exists, it sends the packet to a vehicle nearest to the area. Once the packet reaches within the estimated area the vehicle looks for its neighbours. If the destination exists else it searches for the vehicles within whose neighbourhood the destination exists.

The detailed description of each scheme is as follows. Fonseca et al. [41] have done Qualitative Survey of Position Based Routing (QSPBR) protocols for VANET in highway and urban environment. The topology based protocols are compared to position based protocols. Due to the bottlenecks the Greedy strategy introduce, it offers highest resilient solution and all others have low overhead. Various position based routing protocols like A-STAR, GPSR, GPCR, GyTAR, and MOPR have been studied and findings show that there is no protocol that is best for both urban and highway environment. GPCR and GyTAR are best for urban scenario while GPSR and MOPR meet up to the expectations in highway environments. It is not easy to define when to make transitions between these protocols. It is suggested to propose a new hybrid protocol that meets the requirements of both environments.

Zhao et al. [42] proposed Vehicle-Assisted Data Delivery (VADD) in VANETs in which the authors address the issue of delay tolerant applications in sparsely connected Vehicular networks. As VADD deploys carry and forward technique, there are some basic principles to be followed as mentioned below:

- As much as possible, transmit through wireless channels
- If there is no neighbour moving and packet has to be carried through road, then choose higher speed road
- Dynamic path selection should be executed continuously throughout the packet forwarding process

Fig. 7 shows the scenario in VADD protocol.

According to Fig. 7, vehicle A moving towards East has to forward the packet towards destination in North. A has two options; either to forward the packet to vehicle B which can quickly forward it to vehicle D which is moving towards destination's direction, or vehicle A can forward to vehicle C which is moving towards destination's direction, i.e., North. Based on these two options, there are two different forwarding protocols Location First Probe (L-VADD) and Direction First Probe (D-VADD). L-VADD protocol finds the contact in the destination direction which is closest as its next hop. In Fig. 7, according to L-VADD, the vehicle A will forward the packet to Vehicle B which is closest in the North direction, i.e., the direction of the destination. L-VADD suffers from routing loops at the intersection area. On the other hand, D-VADD protocol finds the vehicle, which is moving in the direction of destination as its next packet carrier. As shown in Fig. 7, in D-VADD vehicle A will select vehicle C, which is moving towards the direction of destination. D-VADD does not suffer from routing loops at intersection. There is another protocol Hybrid Probe (H-VADD)

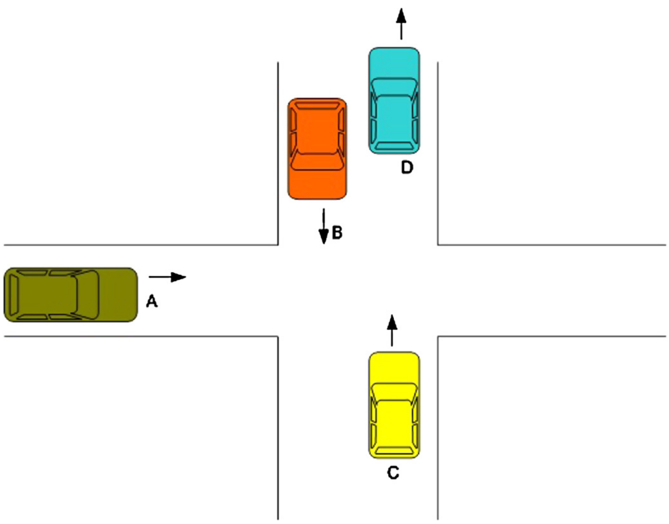

Fig. 7. Selection of next vehicle to forward the packet [42].

which combines the benefits of both protocols. At the intersection, H-VADD behaves like L-VADD with loop detection. As the loop is detected, it uses D-VADD until it exits the current intersection. The simulation work compares the proposed protocol with DSR, the epidemic routing protocol and GPSR, which is simple carry and forward protocol. The simulation results prove that VADD protocols outperform these protocols in terms of PDR, data packet delay and protocol overhead. Amongst the VADD protocols, H-VADD performs best. But the power control with varying transmission range depends upon vehicle density, which needs further investigation [42].

Liu et al. [43] proposed Relative Position Based Message Dissemination (RPB-MD) protocol to disseminate messages more efficiently. Instead of single node, RPB-MD considers all vehicles in ZoR as destinations of messages. It also assumes that vehicles obtain relative distance between neighbours through GPS position information. To make the candidate nodes hold the message with high reliability and to ensure high PDR and low delivery overhead, a Directional Greedy Broadcast Routing (DGBR) is proposed. The time parameters are designed adaptively based on message attributes and local vehicular traffic density which guarantee efficiency. The proposed protocol is robust to traffic density and relative distance accuracy. This protocol is applicable only to highway scenario and needs to be revised to ensure real life working in urban city scenario.

Campolo et al. [44] proposed Augmenting Vehicle to Roadside connectivity in Multi-channel (AVRM) VANETs. In order to cover up the sparse RSU, the paper proposed to design techniques by supporting the spreading of network initialization advertisements from RSUs jointly considering the features and constraints of WAVE. It uses the time, space and channel diversity to improve the efficiency and robustness of network advertisement procedure in urban scenarios. The proposed solution exploits the repetition of Basic Service Set (BSS) advertisements during the Common Control Channel (CCH) interval. It uses the low overhead and flexible WAVE-mode Short Message Protocol (WSMP) packets. With slight modifications in it, the proposed protocol used packets already available to CCH. Simulations were carried out with different parameters like RSU density, vehicular networking technology, penetration rate, data rate and packet size to show the efficiency and effectiveness of the proposed solution. WSMP packets could reduce the overhead and increase the reliability of the link, which is not being explored to its full potential.

Briesemeister et al. [45] proposed Disseminating Messages among Highly Mobile Hosts (DMHMH) based on inter-vehicle communication in which they put forward a simple geocast scheme. When a vehicle receives a packet it does not immediately rebroadcast it but waits for some time and then makes a decision regarding rebroadcasting. The waiting time depends on the distance of the vehicle from the sender. As the distance increases, time reduces and is smaller for more distant vehicles. Hence the nodes at the border of the range of sender take part in dissemination of packet more quickly. After the waiting time expires if the sender vehicle does not receive the same message from another vehicle then the sender vehicle broadcasts the message. There is a maximal-hop-number threshold to limit the scope of flooding. The major advantages of this protocol are that it avoids packet collision and reduces the number of rebroadcasts.

Maihofer et al. [46] proposed an Abiding Geocast which is time-stable geocast for ad hoc networks. In this scheme, the authors proposed special geocast where the packets are delivered to all the vehicles that are sometimes inside the geocast destination region during their geocast lifetime. Three solutions proposed by the authors are as follows

- Server will store the geocast messages
- An elected node inside geocast region will store the messages
- For the packets destined to its location, each node stores all the geocast packets and also keeps the neighbour information.

Cenerario et al. [47] proposed A Content Based Dissemination Protocol (CBDP) for VANETs. The protocol considered the relevance of data based on encounter probability to decide when rediffusion is needed. The protocol sets appropriate weights to different types of events in the network. It allows dissemination of different types of events, i.e., both static and mobile events occurring in VANETs are supported. The messages that are not necessary for specific users are dropped and this is done by rediffusion. It not only saves time but minimizes the network usage. The proposed protocol can be deployed to any kind of vehicular network if the following attributes are communicated as part of information of the events

- Current Position
- Direction Reference Position
- Mobility Reference Position
- Last diffusion position
- Hop number

This information takes only few bytes and can be easily set. The proposed protocol is implemented in Vehicular Event Sharing with mobile Peer-to-peer Architecture (VESPA) system [48–50]. It allows sharing among vehicles and also applies data management techniques in VANETs. The simulations are done considering both urban as well as highway scenario. Results show that vehicles receive the information of interesting events well before meeting them. Though there are overheads in this protocol but these are limited.

Borsetti et al. [51] proposed Application level Role Mobility (ARM) framework in which nodes share assignments and associated application level roles. The handover of role is done according to mobility patterns of vehicles. The framework does two tasks namely the dissemination of information to travelling cars and collecting data from RSUs. For each application, a dedicated role handover is provided. ARM selects the node which is best suited to accomplish that particular task. The simulations show that ARM can perform successfully the required operations in fully distributed way. The operations were performed without any need of fixed infrastructure or dedicated nodes. There is overhead involved but it is very low and tolerable.

Table 3 provides a relative comparison of various geographical based routing schemes.

Table 3
Relative comparison of Geographical routing schemes.

	Vehicle density	Speed	PDR	Latency	No. of hops	Distance	Packet Loss	Throughput	Bandwidth	Feasibility
CAR [22]	Medium	Medium	Low	High	ND	High	ND	Low	Low	Low
GSR [23]	High	ND	Medium	Medium	Low	High	ND	ND	Low	Medium
A-STAR [24]	Medium	Medium	Low	ND	High	Medium	Low	ND	ND	Medium
GPSR [25]	Low	Low	High	Medium	Low	Medium	Medium	ND	Low	Medium
CLDP [26]	Medium	ND	High	High	High	Low	Medium	Less	ND	Medium
GPCR [28]	High	ND	Low	ND	High	High	ND	ND	Medium	Low
GRANT [29]	High	Medium	Low	ND	High	Low	ND	ND	ND	Low
GpsrJ+ [30]	High	Medium	Medium	high	Medium	Low	ND	ND	ND	Medium
GyTAR [32]	Medium	Medium	Low	Medium	Low	ND	ND	Medium	Medium	Medium
LOUVRE [33]	Low	ND	Low	High	High	ND	High	Low	ND	Low
CBF [34]	High	ND	High	ND	High	High	ND	ND	ND	Low
LCR [35]	High	ND	ND	ND	Low	High	ND	Low	ND	Low
GeoCross [36]	Medium	Low	Medium	Low	High	Medium	ND	ND	ND	High
GeoSpray [37]	Medium	Medium	Low	Low	ND	ND	Low	ND	High	Low
RIVER [38]	Medium	Low	ND	Medium	Medium	ND	ND	Low	Medium	Medium
GeoSVR [39]	Medium	Medium	High	Medium	High	High	Low	ND	ND	Medium
ROAMER [40]	Medium	Medium	Low	ND	ND	High	ND	ND	Low	Medium
VADD [42]	High	High	Medium	Low	Medium	High	ND	ND	Low	Medium
RPB-MD [43]	High	High	High	Medium		ND	ND	High	Medium	High
AVRM [44]	High	Medium	Medium	High	ND	Medium	Medium	ND	High	Medium
DMHMH [45]	Low	High	Medium	High	ND	High	High	Low	Low	Low
Abiding Geocast [46]	High	Medium	Medium	High	Low	High	High	ND	Medium	Medium
CBDP [47]	ND	High	MEdium	MEdium	ND	Medium	ND	ND	ND	Medium
ARM [51]	High	Medium	High	Low	ND	ND	Low	High	High	High

ND = Not Determined.

3.1. Discussion

Position based routing approach performs better in PDR and latency as compared to AODV and DSR but loss of connectivity in path selected by algorithm leads to the failure of GSR [23]. By traffic awareness A-STAR selects paths with higher connectivity hence packet delivery could be improved further by 40% [24]. Since GSR uses recovery strategies to bypass dropped node, it selects longer routes and reduces packet drop rate but DSR being more aggressive, uses the node with largest progress and leads to more packet drops [19]. GPSR routes packets nearer to the destination hence achieves higher data packet delivery up to 97% as compared to 85% with DSR [25]. GPSR performs well on connectivity graphs without planarization. Since it removes all the links witnessed by planarization, it incurs higher stretch whereas CLDP outperforms GPSR by removing fully cross links [26].

GPCR has higher PDR but at the expense of higher number of hops and higher latency as compared to GPSR [29]. GRANT is able to find more routes without recovery than greedy routing. The performance is better than greedy routing with junction detection also. The recovery in GRANT is scarcely used and does not increase the average path length considerably [29]. As the density of the nodes in network increases, the network becomes more connected resulting in increase in PDR in GpsrJ+ [30]. There is smoother decrease in hop count in GpsrJ+ than GPCR because in GpsrJ+, nodes do not necessarily have to go through junction nodes [30]. The E2ED in GyTAR is much less than GSR in all configurations because GyTAR uses improved greedy strategy to forward packets between junctions, so the number of hops involved for delivering packets is reduced. GyTAR does not keep track of an end-to-end route before sending packets, hence route is discovered progressively when relaying data packets from source to destination [32]. The hop count and delay of LOUVRE is very less because LOUVRE rarely encounters local maxima therefore does not have to use recovery mode [33]. The PDR of CBF is very high because it only requires retransmissions to resolve collisions which occur when two nodes select same MAC slot [34].

LCR with lazy removal of cross links reduces messaging overhead up to three times less than CLDP.

Messaging overhead per node is relatively insensitive to network size in LCR [35]. GeoCross explores path in a greedy way. It switches to recovery mode when the greedy mode fails. Because of this GeoCross yields suboptimal paths which leads to higher hop count and low packet delivery [36]. Although GeoSpray initiates more transmissions, it has much lower bundle drop rates across all simulations. This is because GeoSpray has a module which is responsible for explicitly clearing delivered bundles across network nodes [37].

Average packet delay is decreased with increase in car density from 2 to 6 s in city and 2.5 to 5.5 s in highway scenario using CAR. CAR performed even better than combination of CAR + GPSR [22], whereas much lower latency is observed using GeoCross where it is about 250 ms and further decreases to 100–120 ms as number of nodes increases from 180–200. Because as the number of nodes increases the connectivity to the destination increases. GeoCross takes larger strides towards destination in perimeter mode, which decreases latency [36]. The packet throughput of RIVER is up to 222% higher than GPSR and up to 39% better than STAR as it uses optimal greedy strategy [38]. The latency of GeoSVR is less than 0.1 s whereas it is as high as 1.0 s in AODV. The low latency of GeoSVR is because of stateless routing. AODV uses restrictive routing and has to establish a stable route to destination before forwarding the packets hence has high latency [39]. ROAMER is able to maintain low delay even when the number of vehicle density is less since ROAMER does not require route recovery phase to the RSU before data packets are sent [40]. A decrease in average delay is reported with increase in traffic density up to 0.02 vehicle/m.lane [41].

An increase in traffic density to 0.05 vehicle/m.lane had no effect on average delay although RPB-MD kept very high network reachability by adjusting its parameters accordingly to different scenarios. A very high data delivery ratio (95%) at traffic density 0.01 vehicle/m.lane to 0.05 vehicle/m.lane using RPB-MD has been reported [43]. RPB-MD has maintained high data delivery ratio, which decreases from 0.98 to 0.88 as data sending rate increases from 0.2 to 1.0 because only message head broadcasts the message [43]. A similar trend of decrease in data delivery ratio with an increase in data sending rate using epidemic protocol has been reported. However, loop detection by H-VADD protocol prevents some packet being sent to loop vulnerable neighbours and an almost constant level of 0.8 is obtained when data sending rate is increased up to 1.0 [42]. Using MP-Best protocols, node disjoint path routing achieves the same PDR as single path routing for short distance s–d pair because intra flow contention dominates.

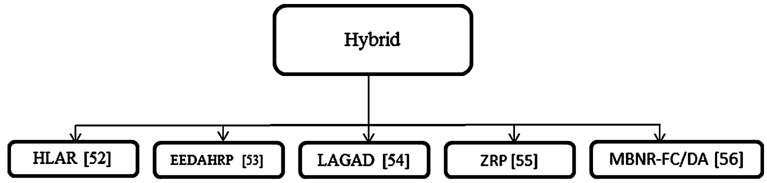

Fig. 8. Classification of Hybrid routing schemes.

PDR of node disjoint path is double as that of single path when packet rate is more than 40 packets per second and source to destination distance is 7 hops. Percent of data packet dropped is up to 0.1% using VADD when data sending rate is 1 or less [42]. Average E2ED is maintained at a constant low level of around 30 s when data sending rate is up to 1 [42]. However an increase in average E2ED is achieved as packet sending rate is increased from 1 to 100 per second. The best node disjoint paths show lowest average delay since node disjoint paths are far away enough and transfer packets with less contention and offset the retransmission delay due to lossy links. Packet loss is reduced 5 times with H-VADD as compared to L-VADD with loop [42].

The RSU detection capability decreases as the penetration rate increases because for any number of RSU, there is higher congestion on CCH caused by beacons [44].

With an increase in number of nodes, network load increases because distance between sender and geocast destination region becomes large [46].

Normally all the vehicles are informed before encountering the event using CBDP and most of these vehicles had enough time to react to warning message received but in case of mobile events it is difficult to warn the vehicle far away. This is because the probability of two vehicles meeting is not very high when these vehicles are far away [47].

ARM is highly accurate in using speed and direction in selecting Carrier as compared to distance based strategy protocols [51]. Campolo et al. [44] explored the flexible WAVE-mode Short Message Protocol (WSMP) packets and could reduce the overhead and increase the reliability of the link, which is not being explored to its full potential.

The power control with varying transmission range depends upon vehicle density, which needs further investigation [42]. There is a need to investigate ways to design an advanced cross-layer between MAC and routing layer to solve the problem of interference, scalability and connectivity in VANETs [43].

4. Hybrid routing

These protocols are designed to take the best of both Topology based and Geographic based routing schemes. Some of major hybrid protocols are categorized in Fig. 8.

Rabayah and Malaney [52] proposed a scalable hybrid routing protocol for VANETs which combines the features of reactive routing and location based geographic routing. In Topology based schemes, the link state information is used for packet forwarding. In these protocols, the performance degrades as the network size increases. In Geographical based schemes, the forwarding decision is based on the position of destination vehicle and position of one hop neighbours. The most important issue in geographic routing is the location error. The authors propose Hybrid Location-based Ad hoc Routing (HLAR) protocol which combines AODV and Expected Transmission Count (ETX) parameters to find the best quality route. The route discovery is done in on-demand basis. If the source knows the route to the destination, the source in Route REQuest (RREQ) includes the location coordinates of both itself and destination. Then it looks at its neighbour table to find any vehicle closer to the destination. If the closer vehicle is available, then the RREQ packet is forwarded, but in case of void region where no closer neighbour is available, the packet is flooded to all the neighbours. This way the RREQ packet reaches the destination, following the same procedure at all the intermediate vehicles. The source node inserts a Time To Live (TTL) field, which is decremented whenever the intermediate vehicle cannot use the location information in forwarding decision. The destination replies if any of three conditions are satisfied, either the destination receives the RREQ from the source for the first time or if the RREQ packet has higher source sequence number or else if the new packet has better quality route available. Another important feature of this protocol is that the broken links are allowed to be repaired locally through Route Repair (RRP) packets. In case of broken links, the intermediate vehicle looks its neighbour table and finds a vehicle closer to the destination. If a closer neighbour is not available, the intermediate vehicle floods the RRP packets with TTL set to the number of hops remaining to the destination. If still the problem is not sorted, the Route Error (RERR) packet is sent to the source. The authors categorize the routing overhead rate Oov into three categories as:

- Initiating overhead rate O_i
- Maintenance overhead rate O_{mn}
- Beacon overhead rate O_b

The authors calculate the O_i for both AODV-ETX and for HLAR. For calculating O_i for AODV-ETX following equation is used:

$$O_i = \frac{N_i S_p}{t} \tag{6}$$

$N_i =$ total number of routing overhead packet transmission for initiating m communication pairs, $S_p =$ control packet size.

The authors used two scenarios namely highway and urban environment and the comparison is made with AODV-ETX and Minimum Traffic Load (MTL). In both urban and highway scenarios, the routing overhead rate is slower for HLAR than MTL and the overhead for AODV-ETX is much higher. This proves that HLAR is scalable and AODV-ETX is not.

Minh et al. [53] proposed E2ED Assessment and Hybrid Routing Protocol (EEDAHRP) in which the end to end delay is given as

$$EEdRDT = RREQT_{tot} + TotMACLd + Tot\,\mu \tag{7}$$

where $RREQT_{tot}$ is total time spent on route discovery processes and TotMACLd is total delay at MAC Layer. If source and destination are separated by n hops, total propagation delay i.e. $Tot\,\mu$ is product of number of hops and average delay per hop i.e. $\mu\,Avg$,

$$Tot\,\mu = n \times \mu\,Avg \tag{8}$$

According to this protocol, the source node S sends packet to Destination node D by unicast if they are in range of each other, otherwise multicast message is sent to far neighbour of S until it reaches D.

Abrougui et al. [54] proposed Location-Aided Gateway Advertisement and Discovery (LAGAD) scheme. The LAGAD has following key features:

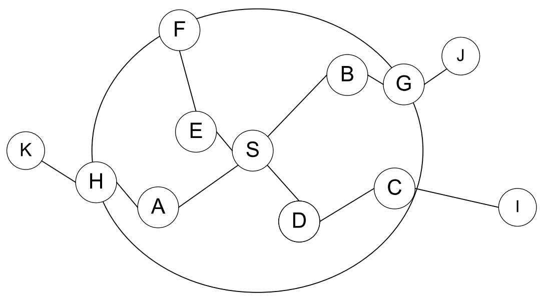

Fig. 9. Routing zone with $\rho = 2$ [55].

- It is built on top of network Layer
- It uses channel diversity
- It is based on location aided adaptation of the advertisement zone of the gateway.

According to the proposed scheme, given the set of gateways and assuming that each car and each base station is aware of its position, the proposed protocol lets each gateway requester car discover nearby gateways and gain sufficient information to route the packets toward the closest gateway while guaranteeing network scalability. The proposed protocol requires no prior configuration and can perform in ad hoc manner. Simulation results show that LAGAD has considerably lower overhead than proactive, reactive and other hybrid approaches. LAGAD gives when relaying data packets from sources to destination gateways. LAGAD has highest delivery ratio of data packets with low E2ED and permits duplicate and ordered data packet reception at the destination gateway. Among all the strengths, LAGAD has weakness in determining efficient radius of gateway advertisement zone.

Beijar has reported that Zone Routing Protocol (ZRP) [55] defines zones containing the nodes that are at most ρ hops away. Nodes are classified as interior, peripheral and external nodes. Those nodes that are less than ρ hops are interior nodes. Peripheral nodes are exactly ρ hops away. The nodes that are farther than ρ hops and don't lie in the zone are external nodes. As shown in Fig. 9 the routing zone with $\rho = 2$ centred at S, the nodes A to H are situated within 2 hop distance from S hence are interior nodes. But nodes I, J and K are outside the zone because they cannot be reached within 2 hops.

Proactive routing component IntrAzone Routing Protocol (IARP) maintains the up to date routing table within the zone. Using route request and route replies IntErzone Routing Protocol (IERP) routes outside the zone are discovered. IARP and IERP are not specific protocols but are family of proactive and reactive routing protocols. When global route discovery is needed Bordercasting Routing Protocol (BRP) is used. Using BRP nodes at the border of zone are directly queried. ZRP uses Neighbour Discovery protocol (NDP) provided by Medium Access Control (MAC) Layer to detect new nodes and link failures. NDP regularly exchanges beacon messages to update its neighbour table. After specific time, if no beacon message is received from a node, it is removed from the table. The protocol performance can be optimized by regulating the number of nodes in a zone and it is done by adjusting the transmission power of nodes.

Huang and Rubin [56] proposed Mobile Backbone Network Routing with Flow Control and Distance Awareness (MBNR-FC/DA) which dynamically elects backbone capable nodes to form mobile backbone (Bnet). MBNR-FC/DA selectively floods the route discovery messages across Bnet. This reduces routing control overhead. In order to further improve the performance, the traffic is guided to traverse less congested areas. The protocol uses both backbone centred and global route discovery processes. The backbone paths are used only where Bnet is unable to cover the whole network area to limit the throughput capacity. In order to improve the overall throughput capacity of links located away from Bnet, flows that use distance less than threshold distance can use non-backbone routes. In order to efficiently utilize the network capacity resources, global route discovery process is invoked. Simulations prove that MBNR-FC/DA has good delay-throughput performance under different backbone coverage levels. Table 4 gives the relative comparison of various hybrid routing schemes in VANETs.

4.1. Discussion

The routing overhead rate of HLAR grows slowly with the increase in network size and network density than other compared protocols proving that HLAR is scalable [52]. With the increase in vehicle density, PDR of HLAR increases because with the increase in density it is easier to establish and repair routes in HLAR [52]. Route discovery time increases with increase in number of nodes in EEDAHRP but this increase is smaller than increase in AODV, mainly because of using end-to-end delay assessment and by using the mechanism that relays the destination node to closer neighbours [53]. Due to low route discovery time and end to end data transfer time, EEDAHRP has fast setting up connection link and average packet loss rate is low so suits better to rapid changing topology and high mobility in VANETs. Similarly a low end to end delay is observed in LAGAD up to 700 nodes [54]. Advertisement in zone adaptation mechanism in LAGAD results in 96% success rate. LAGAD succeeds in maintaining order of sent data packets.

Optimal radius for ZRP is independent of node density [55]. The geographic routing protocols outperform ZRP [56]. Delay-Threshold performance does not change under different levels of backbone coverage in MBNR-FC/DA [56]. Non-hybrid schemes because of having distance threshold equal to 0 have lower throughput capacity than MBNR-FC/DA.

A number of protocols have been proposed to achieve optimal connectivity for rapid and reliable routing in VANETs in urban and highway scenarios. While using different protocols for highway and urban environment, it is not easy to define when to make transition between the two protocols. In case of transition from highway to urban scenario, if the protocol transition is made too soon and the vehicle still has packets to forward to other vehicles in the highway, it would not be able to do so since those nodes are using different protocols. The same would happen in transition from urban to highway [23]. Therefore, a new type of hybrid protocol needs to be designed aimed to adapt itself to the type of environment that solves the protocol transition issue.

Table 4
Relative comparison of Hybrid routing schemes.

	Vehicle density	Speed	PDR	Latency	Throughput	Bandwidth	Feasibility
HLAR [52]	Medium	Medium	Medium	Low	ND	Medium	High
EEDAHRP [53]	Medium	ND	Medium	Medium	Low	High	Medium
LAGAD [54]	ND	ND	Medium	Medium	Medium	ND	Medium
MBNR-FC/DA [56]	ND	Low	High	Low	High	Low	High

ND = Not Determined.

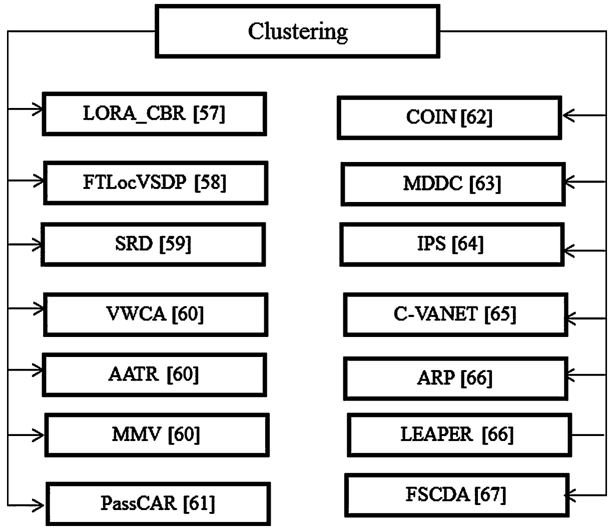

Fig. 10. Classification of Clustering based routing.

Message delivery delay is linearly co-related to message delivery distance, i.e., larger the distance more will be delay. As the density of vehicles and their velocity increases the delivery delay decreases but there is an upper bound on this linear relationship [52]. Optimal deployment of RSU is still to be achieved in high density scenario and on highways, where velocity limit is higher.

VANET is characterized by high speed of nodes and fast changing topology. Geographic protocols used the position of destination to send messages whereas hybrid protocols combined the use of reactive routing with geographic routing. But how to maintain link stability with rapidly changing topology is still to be answered.

5. Clustering based routing

In these type of routing schemes, amongst many vehicles in the cluster area one nodes becomes CH which manages rest of nodes called cluster members. If one node falls in communication range of two or more clusters, it is called as border node. Different protocols are proposed differing in how the CH is selected/elected and the way routing is done. Some of the prominent protocols in this category are described in Fig. 10.

Santos et al. [57] presented Performance evaluation of routing protocols and proposed cluster based flooding protocol for VANETs called LORA_CBR. There is a classification of nodes into CHs, gateway or cluster member. There is one CH per cluster. If a node is connected to more than one cluster, it is termed as gateway. The information about the members and gateways is maintained by CH. Routing of the packets from source to destination is done in greedy manner. In case the location of destination is not available, the Location Request (LREQ) packets are sent by the source. Only CH will disseminate the LREQ and Location Reply (LREP) messages. The protocol is similar to AODV but the difference is that only CH will disseminate the messages. Simulations are done for both urban and highway scenarios. Results clearly show that network mobility and size affect the performance of AODV and DSR more than LORA_CBR.

Abrougui et al. [58] proposed an efficient fault tolerant service discovery protocol for VANETs. Due to faulty components between service provider and service requester there is decrease in dropped connections and service request satisfaction. This decrease in connections and service request satisfaction can be improved by fault tolerant techniques. In Fault Tolerant Location based Vehicular Service Discovery Protocol (FTLocVSDP) requester specifies the region of interest within the request and the protocol uses discovery of location based services. In the region of vehicular network, the protocol uses infrastructure support consisting of clusters of roadside routers. In order to improve the service discovery efficiency, the service discovery messages are integrated into network layer and use channel diversity. Earlier version of LocVSDP relies on wireless backbone or roadside routers but in enhanced version roadside routers are clustered around service providers, the congested areas of vehicular networks and discontinuous areas. In the simulation of enhanced LocVSDP and FTLocVSDP the three parameters are used namely success rate, average response time and bandwidth usage. Comparing with protocol which does not consider fault tolerant techniques in the roadside router, there is improvement of 50% in communication link failure scenario.

Schwartz et al. [59] proposed a directional routing protocol for VANETs. The proposed Simple and Robust Dissemination (SRD) protocol works well in both dense and sparse networks. The major problem in dense networks is broadcast storm and the SRD approach deals with it by using optimized broadcast suppression technique. For sparse networks where there are not many vehicles, the protocol uses store and carry forward communication technique. The protocol assumes that there are no RSUs available. Vehicles are classified in two states, cluster tail and non-tail. In the tail state, the vehicle broadcasts the received message with the tail flag in the message, set to true. The vehicles in the tail state stores all the messages. If there is no connectivity, the tail is responsible to propagate the message in store and carry forward mechanism. When a vehicle does not receive a message from the vehicle farther then the vehicle goes from non-tail state to tail state. In the non-tail state also all the messages coming from tail are stored. In order to reduce the redundant transmissions, non-tail vehicle rebroadcast the received messages with Optimized Slotted 1-Persistence technique. According to Optimized Slotted 1-Persistence technique, vehicles can only cancel the rebroadcasts when the vehicle receives an echo from any of the vehicle further in the message direction. Results of simulations when compared with DV-CAST proved that SRD outperforms DV-CAST for delivery ratio. SRD also achieves lower load in the network. In highly dynamic scenario, where the vehicles move frequently to different roads, SRD performs better with respect to robustness.

Daeinabi et al. [60] proposed an efficient clustering algorithm named VWCA that takes into consideration the number of neighbours based on dynamic transmission range, the direction of vehicles, the entropy and the distrust parameters. The proposed algorithm selects CH and increases stability and connectivity and also reduces the overhead in the network. Using VWCA communication overheads, required for joining to a new cluster in network, decrease because the membership duration for each vehicle increases. Since for communication vehicles should be located in each other's transmission range the authors propose another algorithm for designing an Adaptive Allocation of Transmission Range (AATR). In AATR algorithm, authors define minimum and maximum transmission range because a vehicle may not be located in the range of neighbours and messages do not arrive in their destination on time. The vehicle starts with minimum transmission range and looks to find a neighbour. If it does not exist, it iteratively increases the transmission range till the range is equal to maximum range or vehicle finds a neighbour. VWCA uses distrust value in weighted sum operation which is calculated from Monitoring Malicious Vehicle (MMV) algorithm. MMV detects abnormal vehicle in the system and monitors behaviour of vehicles in the network. These three algorithms namely VWCA, AATR and MMV are good only in highway scenario and their adoptability in city scenario is questionable.

Wang and Lin [61] proposed passive clustering based routing protocol named PassCAR. In passive clustering, a cluster has one CH and multiple clusters can be connected through gateways. Pass-

CAR works in three phases namely route discovery, route establishment and data transmission. During the route discovery phase, suitable nodes are selected which become gateway and CH. These nodes forward RREQ packets. For route establishment, the protocol uses multi-metric election strategy and considers the links reliability, stability and sustainability. Protocol quantifies the links based on parameters of node degree, expected transmission count and link lifetime. Once the route is discovered the destination node replies the RREP packet to the source node. The data transmission is done through the established path. The simulation results prove that PassCAR is superior to other protocols as it has better PDR and network throughput.

Blum et al. [62] proposed Clustering for Open IVC Networks (COIN) algorithm. In this scheme, authors proposed that the CH is elected based on vehicular dynamics and the driver's intentions. Algorithm also takes into consideration the oscillatory nature of the inter vehicle distances. Simulations show that COIN produces relatively stable structure in VANETs. The overhead is also minimal and under tolerable limits. By analytical results and simulations, it is also proved that average life time of cluster is increased by at least 192% and there is reduction in cluster membership by at least 46%.

Kakkasageri et al. [63] proposed a Multiagent Driven Dynamic Clustering (MDDC) of vehicles in VANETs. By taking into account the parameters such as vehicle speed, direction, connectivity degree to other vehicles and mobility pattern, the proposed scheme forms a moving dynamic cluster between the two intersections. The scheme integrates mobile agents and static agents to deliver a rapid response for dynamic clustering. The simulation parameters are cluster formation time, cluster member selection time, CH selection time and control overhead. The proposed scheme is compared to existing clustering schemes and it is found that MDDC performs better in all aspects. But after crossing the intersection the lane intersection was not considered. Noisy environments, traffic lights, signs at the intersection, more number of lanes per road are some other factors which may influence effectiveness of such system.

Little et al. [64] proposed an Information Propagation Scheme (IPS) for VANETs in which the authors use cluster based message dissemination using opportunistic forwarding. Cluster based routing protocols can achieve good scalability but with some limitations. As the size of VANETs grows and because of high mobility, there are lots of overheads involved in forming and maintaining the clusters. There might also be more delay involved in cluster based methods of routing.

Pan et al. [65] have proposed a Cooperative Communication Aware Link Scheduling for Cognitive VANET (C-VANET) and have investigated the throughput maximization problem in C-VANET under multiple constraints such as

- Cognitive Radio (CR) devices' inherent single-ratio constraint
- The availability of licensed spectrum
- Transmission mode selection
- Link scheduling

The authors classified the links into general or cooperative links. According to the availability of bands at different extended links, extended band pairs are defined and a 3-D cooperative conflict graph is formed. This 3-D graph describes the conflict relationship among pairs. The end to end throughput maximization problem is mathematically formulated. These problems are solved by linear programming. Due to NP-Completeness of finding all independent sets, the cooperative communication aware link scheduling algorithm is proposed. The simulations show that CR capability provides more opportunities for using cooperative communications. The simulations also prove that the performance of link scheduling with properly selected transmission mode is better than the one in which the transmission is relied on one transmission mode.

Li et al. [66] proposed Adaptive Role Playing (ARP) strategy to enable the nodes in each hop to contend to perform the basic functions. Even in the case of existing malfunctioning and misbehaving nodes, reliable and faithful data packet relaying is still achievable. The authors also proposed LEAPER, which enables the nodes in each hop to securely and efficiently follow ARP strategy. LEAPER is resistant to the malfunctioning nodes with security threshold k. Authors defined the constraints on security threshold k as follows

$$k \leqslant \lambda \times L \times nl \tag{9}$$

K must be fewer than the number of nodes in a trust group determined by $\lambda =$ node density; $L =$ length of trust group; $nl =$ number of lanes

$$(k+2)\tau m + (2k+2)\tau v + 3\tau s \leqslant T_d \tag{10}$$

τm = MAC access time; τs = signature creation time; τv = signature verification time; T_d = per-hop latency.

The total delay caused by one data packet $(\tau m + \tau v + \tau s)$, k trust tokens $(k\tau m + k\tau v + \tau s)$ and total trust token $(\tau m + (k+1)\tau v + \tau s)$ must be shorter than T_d

$$\Pr\{\text{Less than } k+1 \text{ misbehaving nodes in a hop}\} \geqslant Ps \tag{11}$$

More than $k+1$ misbehaving nodes in a trust group could plan to relay a tampered data packet to the next hop. Hence k must be big enough to make it impossible to have $k+1$ misbehaving nodes in a trust group. K must be set to any value within ranges determined by the above three factors. With $k = 1$, LEAPER is able to countermeasure the misbehaving nodes, discarding the tempered data packet and enabling the authentic data packets to be relayed. Simulations prove that with $k = 1$, LEAPER can ensure both reliable and faithful data packet relaying in the face of up to 30% misbehaving and malfunctioning nodes. With k set to higher values, LEAPER can handle the plans among the misbehaving nodes better and remove any tempered data packets from VANETs.

Scheuermann et al. [67] proposed a Fundamental Scalability Criterion for Data Aggregation in VANETs (FSCDA) in which they showed that for any aggression scheme, its bandwidth profile must be $o(\frac{1}{d^2})$ to be considered scalable. Authors also proved that for arbitrary $\varepsilon > 0$ a bandwidth profile in $\Omega(\frac{1}{d^{2+\varepsilon}})$ can be achieved. Here d is distance between source of information and interested vehicle.

Table 5 describes the relative comparison of various Clustering based routing schemes in VANETs.

5.1. Discussion

The performance of LocVSDP is affected negatively by presence of Roadside Router failures. This is because of interruption of service requests during the location based request propagation phase. This is also due to interruption of service messages during reply propagation phase. These problems don't occur in FTLocVSDP so the success rate in FTLocVSDP is 70% up to 100 nodes, which is 50% higher than LocVSDP. But the bandwidth usage and response time is higher at the same time [58]. In other routing protocols the collisions become severe and result in low PDR in low density scenario [59]. The VWCA protocol is designed in such a way that it improves security of the network [60].

PassCAR improves PDR by an average of 45% as compared to other protocols because of using node degree as routing metric, which increases the probability of forwarding RREQ packets per hop. This in turn increases the discovery of routing path [61]. AATR improves network connectivity and increases message transmission probability. SRD being simple protocol puts lower load on the

Table 5
Relative comparison of clustering based routing.

	Vehicle density	Speed	PDR	Scalability	Throughput	Cluster lifetime	Bandwidth	Feasibility
FTLocVSDP [58]	Low	ND	Medium	High	High	High	High	High
SRD [59]	High	High	High	Medium	High	Medium	High	Medium
VWCA & AATR [60]	Medium	High	High	High	ND	High	High	High
PassCAR [61]	High	High	Low	ND	Medium	Medium	Low	Low
COIN [62]	Medium	Medium	Medium	Low	Low	High	Low	Medium
MDDC [63]	Medium	Low	Medium	Medium	Medium	High	High	Medium
IPS [64]	Medium	High	ND	Low	ND	High	ND	Medium
C-VANET [65]	Low	High	ND	High	Medium	Medium	High	Medium
LEAPER [66]	High	Medium	Low	Medium	Low	ND	High	Low

ND = Not Determined.

network and has higher delivery ratio. SRD copes up well with simultaneous broadcasts in low density scenario and hence has higher PDR. The clustering protocols improve throughput of the network, but there is a decrease in PDR as the number of vehicles increases. In PassCAR there is a decrease in PDR and throughput with increase in velocity with PDR is around 80% for 250 vehicles and is reduced to 70% for 350 vehicles in PassCAR [61]. The clustering protocols have very long connectivity in urban areas and can strengthen security on highways. The COIN protocol imparts stability in clustering protocols [62]. In COIN there is slow rate of cluster creation whereas in other protocols, because of high rate of clusterhead election, the number of clusterhead forming exceeds COIN [62]. As the number of vehicles increases CH selection time gradually increases. This is because stable clustering scheme requires more packet buffering while forwarding a packet [63].

Maximum propagation rate is sum of vehicle velocity and speed of message propagation in dense traffic conditions whereas minimum propagation rate is speed of carrier vehicle in sparse condition because it is difficult to form data path in such conditions [64].

The deviation of vehicle speed in C-VANET leads to performance degradation of link scheduling because speeding up or slowing down leads to change in network topology of C-VANET [65]. There is a decrease in gateway connectivity with decrease in gateway density. Path lifetime increases with decrease in node and gateway density. The reason is that when node density decreases, there are fewer nodes in close proximity to connect and form fewer paths, hence lead to increase in path lifetime.

Resistant to malfunctioning nodes with any security threshold k in LEAPER ensures reliable data packet relaying [66].

Kakkasageri and Manvi [63] proposed a scheme that integrates mobile agents and static agents to deliver a rapid response for dynamic clustering. After crossing the intersection the lane intersection was not considered. Noisy environments, traffic lights, signs at the intersection, more number of lanes per road are some other factors which may influence effectiveness of such system.

Schwartz et al. [59] proposed a directional routing protocol for vehicular environments. It needs improvement for better performance with regard to E2ED. The proposed scheme can use power control mechanisms to further decrease the network load in dense scenarios. There is a need to reduce the number of communications and provide aggregate information to the drivers.

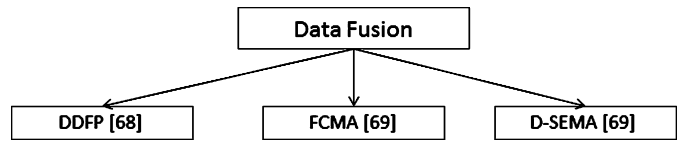

Fig. 11. Classification of Data Fusion schemes of VANETs.

6. Data fusion based routing

Data fusion can be distributed into network and executed on nodes which reduce data from redundant nodes. It fuses the information from complementary nodes to get complete view from cooperative nodes. Consequently only the inference of interest is sent. Some of Data fusion schemes having applicability in routing are categorized in Fig. 11.

Wagh et al. [68] studied the data fusion problem in Driver-in-the-Loop Vehicular Cyber-Physical Systems (VCPS) in which the message is composed of Data Elements (DE). This message has flexible structure. The message can be divided into two parts namely as essential part and auxiliary part. The essential part consists of DEs without which the message is of no use. All the messages must reach the driver for whom the message was generated. The auxiliary part contains DEs that are beneficial if and only if the essential part is available to the driver. But the limitation is that there is limited transmission capacity and limited number of messages can be sent. Within these constraints, to maximize the total utility of complete or partial messages that reach the receiver is to be achieved. The authors have formulated a Basic Driver-in-the-Loop Data Fusion Problem (DDFP) and have proved BDDFP to be NP-Complete. For solving BDDFP four strategies have been proposed namely Knapsack Problem-based Strategy (KPS), Flexible Composition-aware Strategy (FCS), Fine-grained FCS (FFCS) and Data Element-Domain Strategy (DDS). Large simulations have been performed and the algorithms are found out to be efficient. Amongst the proposed four protocols, simulations results show that FFCS has best performance. The authors have also studied the problem for the Multi Seder Single Receiver and Single Sender Multiple Receiver models.

Zhang et al. [69] have proposed a multilevel information fusion approach for road congestion detection in VANETs. The proposed approach combines the feature level information fusion with decision level information fusion. By using Fuzzy Clustering based Message Aggression (FCMA), local atomic messages are classified into different message clusters and abnormal feature is extracted.

Table 6
Relative comparison of data fusion based schemes in VANETs.

	Vehicle density	Speed	Bandwidth	PDR	Scalability	Feasibility
DDFP [68]	Medium	Medium	Low	High	High	High
FCEMA & DSEMA [69]	High	Low	Medium	Low	High	Medium

ND = Not Determined.

Table 7
Detailed comparison and analysis of various routing schemes.

Algorithm, year	Routing approach	Path type	Position verification	Opportunistic	Layer supported	Clustering	Directional antenna	Control packet overhead	Over relay	Environment applicable	Latency	Deployment strategy	Energy efficiency	Load balancing	Coverage & connectivity	Scalability	Mobility	Reliability	Communication metric	Privacy protection
RWP, 1998	–	–	N	N	–	N	–	–	–	U & H	–	–	N	N	–	–	Y	–	–	N
GSR, 2003	Geographic		N	N	–	N	–	–	–	U	–	–	N	N	–	–	–	–	HG	N
COIN, 2003	Reactive	Unicast	N	N	–	Y	–	–	–		–	–	N	N	–	–	–	–	–	N
A-STAR, 2004	Geographic	Unicast	N	N	–	N	–	–	–	U	–	–	N	N	–	–	–	–	–	N
LORA_CBR, 2005	Reactive		N	N	–	Y	–	–	–	U & H	–	–	N	N	–	–	–	–	HG	N
CAR, 2007	Geographic	Singles path	N	–N	–	N	–	–	–	U & H	–	–	N	Y	Y	–	–	–	–	N
PBR, 2007	Predictive	–	N	N	–	N	–	–	–			–	N	N	–	–	–	–	–	N
SADV, 2007	Reactive	Multi-path	N	N	–	N	N	–	–	U & H	–	–	N	N	–	Y	Y	Y	HG	N
VADD, 2008	Reactive	Single path	Y	–	–	N	N	–	–	U & H	–	Carry and forward	N	N	–	Y	Y	Y	–	N
OC-MAC, 2008	–	–	–	N	cross layer	N	N	–	–	H	–	–	N	N	–	Y	Y	–	–	N
MoVES, 2008	–	–	N	N	MAC to Application	Y	N	–	–	U	–	–	N	N	–	Y	Y	Y	–	N
RBVT-R, 2009	Reactive	–	N	N	MAC	N	N	–	–	U	–	–	N	N	–	Y	Y	–	L	N
ETSI, 2009	–	–	–	N	Network and Transport	N	N	–	–	–	–	–	Y	N	Y	N	Y	Y	–	Y
LAGAD, 2010	Hybrid	–	N	N	MAC	N	N	–	–	–	–	–	N	N	–	Y	Y	Y	–	N
AID, 2011	Reactive	Multi-path	N	N	–	N	–	–	–		*		N	N		–	–	–		N
VWCA and AATR, 2011	Reactive		N	N		Y	–	–	–	H	–	–	N	N		Y	Y	Y	–	N
CATE, 2011	Decentralized		N	Y		N	–	–	–	U										N
SRD, 2011	Reactive	Multi-path	N	N	MAC	Y	N	N	–	U & H	–	–	N	N	–	Y	Y	Y	L	N
VESPA, 2011	–	–	N	N	–	N	N	Y	–	U & H	L	–	N	N	–	N	–	–	L	N
ARM, 2011	Reactive	–	–	–	Application	N	N	L	–	U & H	L	–	N	N	–	Y	Y	Y	–	N
TBR, 2011	Reactive	–	N	Y	–	N	N	–	–	U	HG	quota based	N	N	–	Y	Y	Y	L	N
ARP, LEAPER, 2011	–	–	N	N	–	N	N	–	–	U & H	–	–	N	N	–	Y	Y	Y	L	N
FLUTE, 2012	Reactive	Multi-path	N	N	–	N	Omni directional	–	–	–	–	–	N	N	–	N	–	N	–	N
2012	Reactive		N	N		Y	–	–	–		–	–	N	N	–	Y	Y	Y	–	N
FTLocVSDP, 2012			N	N		Y	–	–	–		–	–	N	N		Y	–	Y	–	N
RPB-MD, 2012	Reactive	Multi-path	N	N	–	N	N	N	–	H	–	–	N	N	–	Y	Y	Y	L	N
HLAR, 2012	Hybrid	Single path	N	N	MAC	N	N	Optimal	–	H	L	On Demand	N	N	HG	Y	Y	Y	L	N
OLSR, 2012			N	N	PHY/MAC	N	–	–	–	U	–	–	N	N	–	–	–	–	L	N
eMDR, 2012	Reactive	Multi-path	N	N	MAC	N	N	–	–	U	–	–	N	N	–	Y	Y	Y	L	N
Qos Aware, 2012	Reactive	–	N	N	layers 2 and 3	N	N	N	N	U	–	–	N	N	–	N	–	–	L	N
ROAMER, 2012	Reactive	–	N	N	–	N	N	–	–	U & H	–	–	N	N	–	Y	Y	Y	L	N
EEDAHRP, 2012	Reactive	–	N	N	–	N	N	N	–	–	–	hybrid	N	N	–	–	–	–	L	N
DDFP, 2012	–	–	–	N	–	N	N	–	–	–	–	–	Y	Y	–	–	–	–	L	N
WAVE, 2012	–	–	–	–	–	N	Y	–	–	U & H	–	–	–	–	Y	Y	Y	Y	Y	Y
CoTEC, 2013	Reactive		N	Y		N	–	–	–		Y	–	N	N	–	N	Y	–	L	N
GeoSVR, 2013	Reactive	Single path	N	N	N	N	N	N	N	U	L	greedy	N	N	–	–	Y	–	L	N
RF-GPS	–	–	Y	N	–	N	N	–	–	U & H	–	–	Y	N	–	Y	Y	Y	HG	N
PassCAR, 2013	–	–	N	N	–	Y	N	–	–	U & H	–	–	N	N	–	Y	Y	Y	L	N
FCMA, D-SEMA, 2013	–	–	–	N	–	N	N	–	–	–	–	–	Y	Y	–	–	–	–	L	N

U = Urban, H = Highway, U & H = Urban and Highway both, No = N, Yes = Y, Low = L, High = HG.

Event probability prediction and message credibility is defined and Basic Probability Assignment (BPA) is calculated. This BPA value of evidence is an abnormal aggregation message. To detect the road congestion event, authors used the modified BPA based Dempster–Shafer (D–S) evidence reasoning method. The highlight of FCMA is that it can exactly distinguish different traffic conditions in adjacent two way lanes. Authors have proposed another algorithm named D–S Evidence Message Aggression (D-SEMA) that removes the false abnormal feature information caused by the traffic lights. Simulations show that the proposed multilevel information fusion approach achieves high accuracy of road congestion information and reduces traffic load in the network significantly. Table 6 provides the relative comparison of various data fusion based protocols in VANETs.

6.1. Discussion

An increase in total utility with FFCS and FCS protocols with an increase in the percentage of auxiliary content of message has been observed. FFCS performs better than FCS and KPS by delivering more messages to the receiver. This is because FFCS fully exploits the flexible structure of each message and has more fine grained control over the insertion of auxiliary part. As FFCS has best control over type and size of each message that is picked, its performance is highest [68]. Using FCMA, an improvement in average message aggregation efficiency from 92% to 98% is achieved with increase in message aggregation time from 300 s to 800 s [69]. With low number of left messages and high average message aggregation efficiency FCMA can efficiently detect road congestion [69].

In an extremely loaded situation, a huge amount of data is to be transmitted, so collision of messages will also be large. How to efficiently route the urgent data to all the destined nodes in minimum time needs to be explored further. The use of proxy mobile router also needs further investigation.

No study could be found which used vehicular traces from different scenarios with different node densities to evaluate feasibility and limitations. To the best of our knowledge, there is no research proposal which does comprehensive scalability analysis.

There is a need to consider the use of infrastructure nodes, the GPS, security protocols and sensing information in order to improve the QoS of the network.

7. Analysis and comparison

The routing protocols discussed in this work are compared with 20 parameters in Table 7.

8. Conclusion and future work

Over the last few decades, Vehicular Ad Hoc Networks (VANETs) have emerged as a new powerful technology which can be used in wide areas of applications such as Rescue and surveillance operations, entertainment etc. For all these applications, there is a requirement of efficient routing techniques within the constraints such as high mobility and constant topological changes of the vehicles. This paper provides a complete taxonomy of various existing routing schemes with their relative advantages and disadvantages of each other. For each category of routing, a detailed analysis is provided in the text. Finally, a comparison of various routing schemes with respect to different parameters is also provided. In future, we would implement one of the above defined schemes and compare its performance over the other schemes of its category.

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