Telecommun Syst (2012) 50:267–284
DOI 10.1007/s11235-010-9403-2

DDOR: Destination discovery oriented routing in highway/freeway VANETs^{+}

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Abstract The emerging adoption of wireless communications on surface transportation systems has generated extensive interest among researchers over the last several years. Innovative inter-vehicular communications and vehicle-to-infrastructure communications achieve road traffic safety, ecstatic driving and delightful travelling experiences. Multi-hop information dissemination in vehicular ad hoc networks is challenged by high mobility and frequent disconnections of wireless nodes. This paper presents a new routing scheme for Highway/Freeway VANETs, which consists of a *unicast destination discovery* process, a robust *forward node selection* mechanism and a *positional hello* mechanism. In this paper, no dedicated path is framed in order to prevent frequent path maintenance. In addition, the avoidance of flooding and location services substantially reduces the control overhead. Positional hello scheme ensures connectivity and diminishes control overhead concurrently. Simulation results signify the benefits of the proposed routing strategy (i.e. DDOR) has higher packet delivery ratio, reduced routing overhead and shorter delay compared with previous works.

Keywords VANETs · Highway/freeway · Unicast routing · Location service · Greedy routing · Perimeter routing

1 Introduction

Currently the automotive industry is undergoing a phase of revolution by integrating the capabilities of the new generation wireless network to vehicles. Today, a vehicle is not just a thermo mechanical machine with few electronic devices; rather advancing wireless communication technologies have brought the major transition of vehicles from a dumb moving engine to an intelligent system carrier. A wide spectrum of novel safety and entertainment services are being driven by a new class of communications broadly classified as Intra vehicle (InV) communications, vehicle to vehicle (V2V) communications and vehicle to infrastructure (V2I) communications. Several research communities, including automotive industries, service providers and government agencies have initiated projects for inter vehicular communications (IVC) to explore the potentiality of vehicular ad hoc networks (VANETs). Nowadays great efforts are being placed on research and development of intelligent equipments to meet the needs of modern-day human being. U.S. Department of Transportation employs intelligent transportation systems (ITS) to analyze and inquire about possible applications and to endow with suitable solutions. The two major components of 'ITS' are: (1) Intelligent infrastructures, and (2) Intelligent vehicles. The intelligent infrastructure can realize service scenar-

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Preliminary version was presented in Proceedings of IEEE APSCC 2008.

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ios like freeway management, crash prevention & safety and road weather management. Potential applications like collision notifications & avoidance, driver assistance, and infotainment could be complimented by intelligent vehicles.

A variety of VANET applications are deriving the new development requirement of MAC and network layer protocols. Here we solely focus on a crucial networking problem: routing protocol for VANETs. Till date many state of art MANET (Mobile Ad hoc Network) routing protocols [2, 14, 15, 37, 41] are considered to be possible candidate options for VANET (Vehicular Ad Hoc Networks). The only resemblance which can be tempted to consider is the "Ad hoc mobility" of MANET. However, numerous researchers already surveyed and came to the conclusion that VANET applications [3] are so diverse and its fundamental approach is so dissimilar that it needs another area of research. The major disparity of VANET from MANET is fast vehicles movement and certain mobility behavior. The random movement of nodes in the MANET scenario makes it unmanageable. Unlike MANET, the nodes in VANET have rational patterned movement; confer it to be better controllable. However, VANET is not exempted from challenges. Various new challenges of VANETs have been drawing considerable attentions from pioneering works recently [11, 22, 23, 44].

This paper proposes a position based routing protocol called the Destination Discovery Oriented Routing (DDOR), specifically designed for Highway/Freeway VANETs. The aim of our protocol is to reduce routing overhead and end to end delay, while maintaining higher packet delivery ratio. We have designed a new hello mechanism called positional hello which works with periodic hello. It reduces undesired hello messages sent by nodes which are not the source, the destination or the forwarding nodes. Our unicast destination discovery mechanism fetches the destination information (i.e. relative direction of the destination from the forwarding nodes) without utilizing any location service. In order to send request message we choose unicast over broadcast as reliable delivery of broadcast messages is not guaranteed. Our proposed algorithm SNESA (Smart NExthop Selection Algorithm) finds the farthest forwarding node by considering reliable delivery of packets.

The rest of the paper organized as follows: In Sect. 2, different challenges faced by VANET routing protocols and the corresponding motivations are discussed. In Sect. 3, a survey on different MANET/VANET protocols are presented. In Sect. 4, we elaborate our system model and protocol design. Performance evaluation and comparison are made in Sect. 5. Finally this paper concludes with some remarks in Sect. 6.

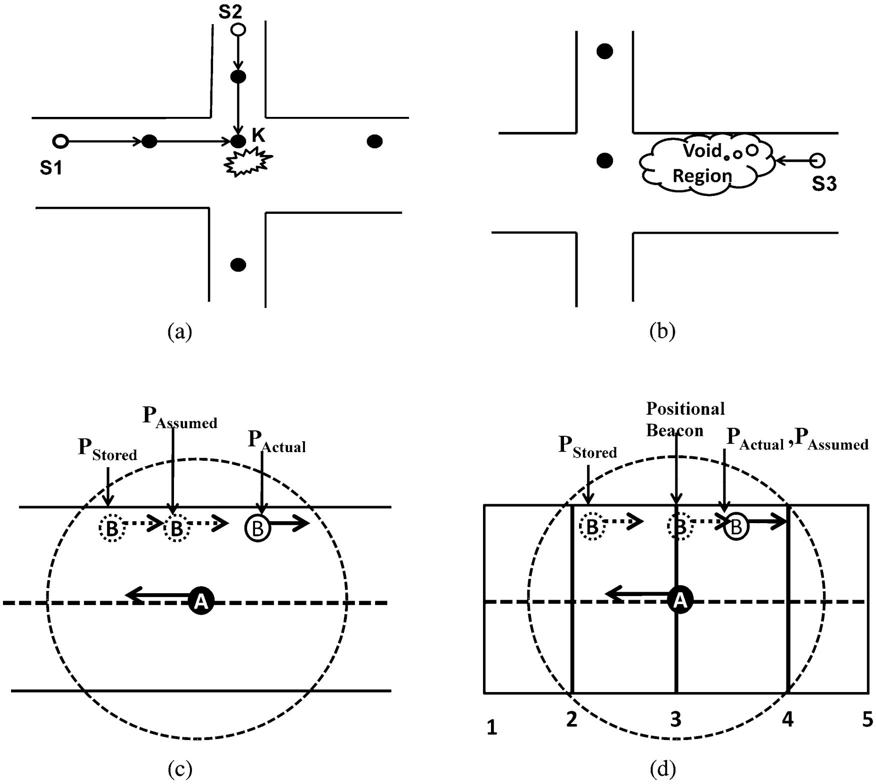
2 Challenges of VANET routing protocols and motivations

2.1 Flooding

Unlike conventional ad hoc networks, VANETs experience rapid link disconnection and a certain type of network topology scenarios due to higher velocity and a specific mobility. Route establishment and route maintenance are crucial aspects of topology based protocols like DSR [14] and AODV [37]. Flooding is the means by which Route Establishment and Route Maintenance is incorporated. Position based routing protocol like GSR [22] depends on reactive location service [16] to obtain the position of the destination. Such location service is similar to the requesting mechanism of DSR [14] and it relies on flooding. In Fig. 1(a), node 'K' is an intersection node. It may receive flooded request messages sent by the source 'S1' and 'S2' simultaneously which leads to a collision and request messages cannot reach to the destinations. In addition, flooding may suffer from void region problem [15]. In Fig. 1(b), the source 'S3' come across a void region. However, after sending flooded request packets, it could remain silent even if a node comes to the neighborhood afterwards. Hence no route establishment is possible for the collision or the void region case. Intrinsically, flooding triggers the so called broadcast storm problem [34]. When the distance between the source and the destination escalates, occurrence of such hitch is more apparent. However, it is observed that the efficient adoption of IEEE 802.11 RTS-CTS-DATA-ACK mechanism of unicast messages protects the packets from collision and explicitly acknowledges the sender/forwarder about the reliable delivery of packets. In void regions, RTS packets are rebroadcasted until a response in terms of CTS is received. This ensures a reliable packet delivery if a node is sighted in the void region at some point. These findings motivate us to propose the unicast destination discovery process.

2.2 Location service

Location service [13, 16, 20, 26] is the vital necessity for many position based routing protocols [15, 23, 40]. By exercising such mechanism, nodes are informed about the destination position. Location services like HLS [17] and GLS [9] necessitate great deal of design complex further. As multiple nodes work in tandem to accomplish such process, the integrity of those protocols possibly could be at stake for high mobility scenarios. This is because a single node has to keep track of many nodes. Apparently reactive location service is simpler in design. It utilizes flooding to know the position information of the destination. Already we have discussed the drawbacks of flooding. Unlike flooding, we have regulated an alternative mechanism to facilitate the source to



(a) (b)

(c) (d)

Fig. 1 (**a**) Request packets due to flooding are sent by S1 and S2 collide at K. (**b**) Request message of source S3 could not be retransmitted due to void regions. (**c**) Position information with periodic hello. (**d**) Position information with periodic and positional hello

acquire the relative direction information of the destination. Our unicast destination discovery process will achieve this purpose. In Sect. 4, this process will be elaborated.

2.3 Periodic beaconing

Hello/Beacon message is indispensible for traditional position based routing protocols to know the neighboring nodes' positions, velocities and moving directions. The beacon packets are reasonably small in size and it normally does not augment significant network overhead. But in high density circumstances, aggregating those information could be cumbersome and superfluous. Out of 1000 nodes 100 nodes may be involved in communication. In such high density scenarios, the frequency of periodic beacons can be reduced. Apparently delayed receipt of beacons hinders the credibility of position information. In Fig. 1(c), node 'A' has to send data towards left. Node 'B' is chosen as a forwarding node from its current assumed position (i.e. P_{Assumed}). The 'P_{Assumed}' position of B has been found from its stored position (i.e. P_{Stored}) and stored velocity information. The stored position of 'B' is outdated when the frequency of periodic beacons is kept low. Now node 'B' may be present at an illegitimate position (i.e. P_{Actual}). Here node 'A' has selected a wrong forwarding node 'B' as it does not receive any recent beacon from it. This motivated us to propose a new hello mechanism, called "Positional Hello". Unlike periodic hello, positional hello broadcasts only when certain designated position (i.e. *Milestone*) is reached. In Fig. 1(d), 4 vertical lines crossing the road are termed *Milestones.* Here node 'B' sends a beacon (i.e. 3rd positional beacon in the Fig. 1(d) before being positioned at P_{Actual}. Hence node 'A' can have the knowledge of the position and high mobility state of node 'B'. So there will be a fair determination procedure for a proper forwarding node accordingly. However we have used periodic beacon with longer beacon interval along with positional hello.

2.4 Gray zone problem

In routing protocols in VANET a source/forwarder chooses a forwarding node before sending a packet. The forwarder is usually selected based upon its position. However the designated forwarder may leave the transmission range of the sender or acquires a position which is not in the legitimate packet forwarding direction. This is called the Gray Zone Problem [24]. In our proposed Smart NExt Hop Selection Algorithm we choose the farthest possible node with the consideration of gray zone problem.

2.5 Scalability

Further, another key matter of contention is the scalability [1, 7] of routing protocols by means of node density and speed. Yet most protocols are deficient in the proof; either by simulation or by analysis. Consequently we perceive that those protocols do not contemplate on this perspective.

Howbeit in this proposal we have emphasized on scalability issues attributed by node density and continuously we are addressing on some further scalability concerns in the near future.

2.6 Pseudo-stability

Protocols like MURU, AODV-MOPR, and ROMSGP etc. use a prediction scheme to estimate when route breakage will occur. Consider a route is established from the source to the destination involving dedicated intermediate nodes at time 'T0'. If the route passes through intersections, it has to involve nodes placed at intersections. Also the node located at an intersection may go to any of the possible directions. Considering an example that every intersection has four possible directions, at 'T1' time 'n' intermediate intersection nodes will have $(1/4)^n$ probability to keep the same expected route. For example if a source-destination pair involves 4 intermediate intersection nodes, the probability of stability is 0.003906. Hence we consider these protocols as pseudo-stable (i.e. a protocol which establishes a path from the source to the destination using some prediction scheme, but can't maintain the same path due to the presence of intersections) routing protocols. There will be an exception if $\mathrm{T1}-\mathrm{T0} < \mathrm{Md}$, where 'Md' denotes message delivery duration.

Despite most protocols proposed VANET routing protocols in usual nature, we felt special attention is essential to deal with freeway/highway scenarios. In this work, we have laid emphasis on and simulated on highway scenarios. Also we have dealt with high density and high mobility scenarios. In addition to that our positional hello performs optimally in such scenarios. In concern with void regions, we have adopted the well known store and forward approach.

3 Literature review

This section highlights major attempts made in routing protocols in VANET scenarios. Five major categories of routing protocols are reviewed with their respective pros and cons. They are proactive, reactive, position-based, opportunistic, and hybrid type.

3.1 Proactive routing protocols

In proactive routing protocols like DSDV [36] and OLSR [5], a table of source-destination pair should be maintained between all pairs of nodes in the network. For large networks, sharing of such tables generates huge network congestion. Also these protocols suffer from count to infinity problem and oscillation problem. OLSR-MOPR [29] is better than OSLR [5] by its movement predication scheme. However, it suffers from pseudo-stability.

3.2 Reactive routing protocols

Existing reactive topology based routing protocols like DSR [14] and AODV [37] establish dedicated paths from the source to the destination for data transmission. But it is witnessed that paths break early with variable speed of intermediate nodes and change in direction of vehicles. For those broken paths, path maintenance is necessitated which depends on the flooding. Broadcast storm problem [34] may arise due to such phenomenon. Additionally Gray zone problem [24] attributes to most path-break up in reactive routing protocols.

Movement prediction based protocols like AODV-MOPR [27], MURU [30], DYMO [39] and ROMSGP [40] predict the path breakup before precisely a path is broken. Also they predict the alternative routes for the broken paths. Here the problem is that, flooding has to be carried out to discover preferred alternative paths. The cost to identify alternative path is analogous to path maintenance cost here. PBR [31] is an attractive protocol for Internet which uses mobile gateway to connect to Internet. However it won't be able to provide uninterrupted internet connection if nodes are present remote to the mobile gateways.

3.3 Hybrid routing protocols

Protocol like ZRP [2] and its descendant [35] acquire the advantages of both proactive routing protocols and reactive routing protocols. They act proactively within a range and behave reactively beyond that range. So they have better packet delivery ratio compared to both Proactive and Reactive protocols. But fast topology change behavior of VANET does not let the nodes to carry on legitimate information for longer time. Hence it leads to higher network burden. In vehicular networks and particularly in highways, it is a major issue to maintain a proper association between proactive and reactive schemes.

3.4 Position based routing protocols

GPSR [15] is a position based protocol which is the source of many other position based routing protocols [8, 10, 15, 19, 21–23, 27, 28, 42]. Nevertheless we will analyze protocols like GPSR [15], GPCR [23], and GSR [22]. In GPSR, the source is aware of the destination position through a location service [9, 16, 17]. These protocols incorporate perimeter routing when data packets reach to the local maxima. It increases hop counts, routing loops are not eliminated and routing may be done in wrong directions. GPCR [23], GyTar [12] and GSR [22] are three important protocols which work well in city scenarios. But all the position based protocols depend upon location services. In the previous section, we have already discussed different pitfalls of

Table 1 Comparative study of different routing protocols

	1	2	3	4	5	6	7	8	9	10	11	12
DSDV [36]	Y	Y	H	Y	Y	N	N	Y	L	L	L	L
OLSR [5]	Y	Y	H	Y	Y	N	Y	Y	L	L	L	L
OLSR-MOPR [29]	Y	Y	M–H	Y	Y	N	Y	Y	L	L	L	L
DSR [14]	N	Y	L–H	Y	Y	N	N	Y	L	L	L	L
AODV [37]	N	Y	L	Y	Y	N	N	Y	L	L	L	L
AODV-MOPR [27]	N	Y	L	Y	Y	N	N	Y	L	L	L	L
ROMSGP [40]	N	Y	L	Y	Y	N	N	Y	L	L	L	L
MURU [30]	N	Y	L	Y	Y	N	N	Y	L	L	L	L
DYMO [39]	N	Y	L	Y	Y	N	N	Y	L	L	L	L
PBR [31]	N	Y	L	Y	Y	N	N	Y	H	H	M	L
ZRP [2]	OY	Y	M–H	Y	Y	N	N	Y	L	L	L	L
Adaptive ZRP [35]	OY	Y	M–H	Y	Y	N	N	Y	L	L	L	L
GPSR [15]	N	OY	H	Y	N	Y	Y	N	M	L	L	M
GPCR [23]	N	OY	H	Y	N	Y	Y	N	H	L	L	M
GPSRJ+ [19]	N	OY	M–H	Y	N	Y	Y	N	H	L	L	M
GOAFR+ [18]	N	OY	H	Y	N	Y	Y	N	M	L	L	M
GSR [22]	N	Y	L	Y	N	Y	Y	N	H	L	H	M
PP [25]	N	OY	H	Y	N	Y	Y	N	M	L	L	M
DR [4]	N	OY	H	Y	N	Y	Y	N	M	L	L	M
LORA–CBF [38]	N	OY	L	Y	N	Y	N	N	H	L	H	L
GYTAR [12]	N	OY	L	Y	N	Y	N	N	H	M	H	M
SADV [6]	N	N	L–M	Y	N	Y	Y	N	H	H	H	M
VADD [45]	N	N	L–M	Y	N	Y	OY	N	H	M	H	M
CAR [32]	N	Y	L	Y	N	Y	N	N	H	M	H	L
CAR [44]	N	N	L	Y	N	Y	N	N	M	L	H	L
DDOR	N	N	L–M	N	N	N	N	N	H	M	H	M

location services. Gytar depends upon a special location service which needs infrastructures to provide the services. But we believe, it is not suitable for pure ad hoc scenarios. Also Gytar does not solve gray zone problems [24].

3.5 Opportunistic forwarding protocols

In sparse scenarios, various protocols have been proposed. SADV [6] protocol considers the physical presence of gateway nodes at intersections. Although it is quite expensive to install an infrastructure at each intersection, it is quite a noble proposal to put the decision on intersection nodes without affecting the network performance. Here the delay is tolerated to send the packet in the optimal direction. Ironically, it has nothing to say about the changing node density. However, VADD [45] protocol provides a better solution by providing dynamic route selection mechanism considering delay into account. Based upon density, the priority of route is set at each intersection. All protocols which works on sparse scenarios, apply the opportunistic forwarding mechanism. So connectivity can not be guaranteed between the source and the destination. Table 1 provides a comparative study of different routing protocols.

4 DDOR in highway VANETs

In this section, we present our “Destination Discovery Oriented Routing (DDOR)” protocol. In V2V networks two factors namely, (1) fast changing network topology and (2) periodic beaconing exchange, play the essential roles for routing protocols. In VANET scenarios, it is crucial to sus-

Table 2 Meanings of different symbols used in Table 1

1	Table Driven	10	Internet suitability
2	Flooding	11	Scalability
3	Routing Overhead	12	Effectiveness of Sparse Scenario Solution
4	Gray Zone Problem	H	High
5	Pseudo Stable	M	Moderate
6	Location Service	L	Low
7	Routing Loop	Y	Yes
8	Route Maintenance	N	No
9	VANET suitability	OY	Occasionally Yes

tain uninterrupted packet delivery by minimizing the performance snag like delay and network congestion.

4.1 Assumptions

Here we assume that each node is aware of its position through GPS. Also each node is equipped with digital map and has the information knowledge of intersections and dead ends. Position information of neighbors is known to each node through beacons. Each intersection is formed by crossing of two road segments.

4.2 DDOR in a Nutshell

In our previous work [43], we started some preliminary attempts to identify characteristics of a suitable protocol for VANET. In this article, specific vital schemes are further designed and enhanced to enhance the performance of DDOR in Highway VANETs. Here, nodes in the network share their position information through periodic hello and positional hello messages. We adopt a prediction scheme to locate the current position of a vehicle based on the previous velocity information. Each intended source sends the unicast Destination Discovery Request (DDREQ) to the nodes in all possible directions to know the relative direction of the destination by choosing the forwarding nodes. The forwarding node forwards a DDREQ to the opposite direction of packet receipt if it is not located at an intersection. If the node is at an intersection, it sends DDREQs to all the available directions except the direction of receipt. The destination node replies back with a Destination Discovery Reply (DDREP) message upon receiving the request (i.e. DDREQ). Upon receiving a DDREP, the source forwards data packets to the direction of the destination. However, before dispatching any message, a node ensures its safe delivery by utilizing the "Smart Next Hop Selection Algorithm (SNESA)". The destination direction update procedure is incorporated, when either of the source or the destination changes their relative direction.

4.3 HELLO CONTROL: positional beaconing

In a typical road scenario a number of *milestones* are set at different positions. In Fig. 2(a), the vertical lines represent the *milestones*. Each vehicle in the network will be aware of these milestones. As a vehicle crosses a milestone, the 'Positional Beacon' is fired. This means a vehicle fires a beacon upon travelling certain distance (i.e. beacon distance). The analogy of positional beacon with beacon distance is similar to periodic beacon with beacon interval. The problem with slow moving vehicles is that they take longer time to cross two consecutive milestones. Hence there is need of periodic beacon. In Fig. 2(b), it is shown that a slow moving vehicle fires periodic beacon in each beacon interval. By means of this positional and periodic beacon combo scheme, it is possible to keep track of both fast and slow moving vehicles without increasing routing overhead.

4.4 Smart next-hop selection algorithm (SNESA)

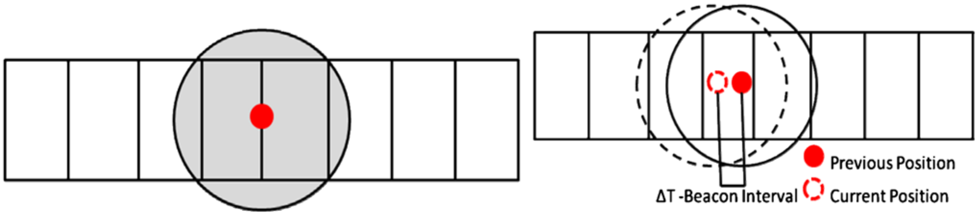
This algorithm safeguards the packets from getting dropped on transit, while ensuring optimum message progress. Before forwarding any message, this algorithm is triggered. It has two steps: (1) Choosing the candidate nodes as a forwarder among all nodes and (2) Finding the best node among the candidate nodes. At time T_0, a neighbor is designated as a candidate if it resides in the relative direction of the destination at T_1 and dwells within the modified transmission range $R1$ $(= R - \Delta E)$ till time T_1. Δt $(= T_1 - T_0)$ is the total transmission time of a message. R is the actual transmission range of a vehicle.

Here,

$$\Delta E = R_{VC} + \frac{1}{2} A * (\Delta t)^2 \quad \text{and} \quad A = \frac{R_{VM} - R_{VC}}{\Delta t},$$

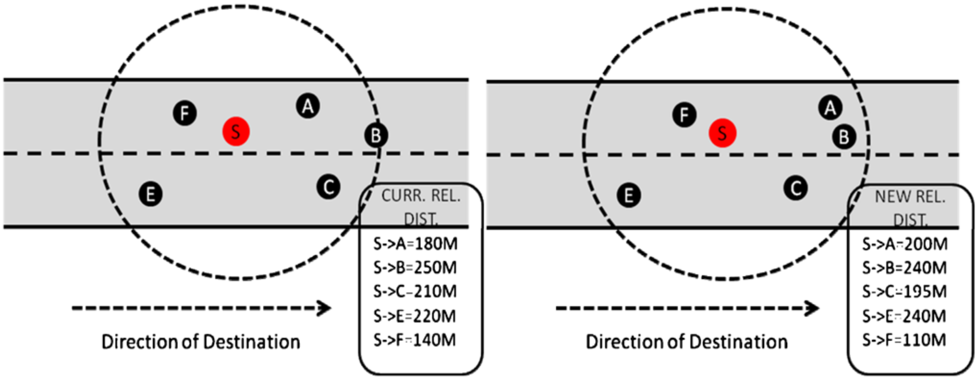
$R_{VC} \rightarrow$ Current Relative Velocity, $R_{VM} \rightarrow$ Maximum Relative Velocity.

Every node is awarded weights based upon the relative distance at time T_1. Those nodes which do not reside in the direction of the destination at time T_1 or do not reside in



(a) (b)

Fig. 2 (**a**) Positional hello broadcasts when the milestone is reached. (**b**) Periodic hello broadcasts when beacon interval expires



(a) (b)

Fig. 3 (**a**) Node positions before transmission. (**b**) Expected node positions after entire transmission time

$R1$ range for entire transmission period will have negative weight. The nodes with positive weight are considered as the candidates. The node with highest positive weight is considered as the forwarder. If no node resides within range $R1$ then actual transmission range R is considered.

In Fig. 3(a) and 3(b), the source node 'S' has 5 neighbors (i.e. A, B, C, E, and F) at time T_0 (i.e. current time) and T_1 (i.e. next time interval) respectively. Here suppose 'S' intends to find a forwarding node in the direction of the destination. Here, the transmission range 'R' is taken as 250 meters. To be a candidate, a node has to be within the transmission range '$R1$' ($= R - \Delta E$) of 'S' for the entire period (i.e. $T_1 - T_0$). And that node has to be in the direction of the destination at time T_1. Here, node 'E' and 'F' are not in the direction of the destination. Although node B is within range of R, it is not within range of '$R1$' at time T_0. So the candidate nodes are 'A' and 'C'. At time T_1, node 'A' is farther than node 'C'. Hence node 'A' is preferred over node 'C'.

4.5 Destination discovery

It is a process similar to route establishment of AODV. We intend not to establish any route from the source to the destination and any sort of flooding or broadcasting is not employed for this task. All messages are carried through unicast transmission. The motive behind this attempt is to exploit the patterned structure of road. Normally naïve flooding creates serious contention and heavy collision in a wireless ad hoc network. Although refined and optimized flooding have been proposed in some literatures, it is still extremely difficult to ensure to be free from broadcast storm problem [34]. We felt and found in our simulations that for long highly dense freeways it is suitable to go for unicast rather than broadcast. The benefits are: (a) avoidance of flooding and flooding issues, (b) reduction of packet collisions due to hidden terminal problems.

Unicast DDREQ messages are dispatched in all available directions from the source while finding a suitable forwarding node. A forwarding node is chosen using SNESA if no intersection is found in the selected direction within the modified transmission range of a node (i.e. $R - \Delta E$). If any intersection is encountered, a node located closest to the centre of the intersection is selected as the forwarder. When the source lies in a road segment (i.e. not at intersection), it sends DDREQs in both front and back directions. If it is placed at an intersection, (i.e. four segments joining) the DDREQ messages will be sent to all road directions joining to the intersection. A forwarder dispatches a DDREQ in the opposite direction of packet receipt, if it is present in a road segment. However, a forwarder located at intersection dispatches the DDREQs to all other directions except the direction of packet receipt putting the signature of the intersection (i.e. intersection Id). The direction values are stored in the header of the DDREQ packets. Any node that receives the DDREQ packet stores the relative source direction. For example, if a node receives a west ward packet, then it stores the source direction as east. Few of the

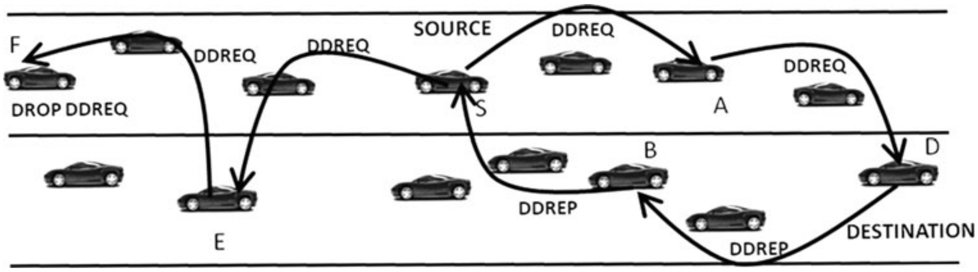


Fig. 4 Destination discovery

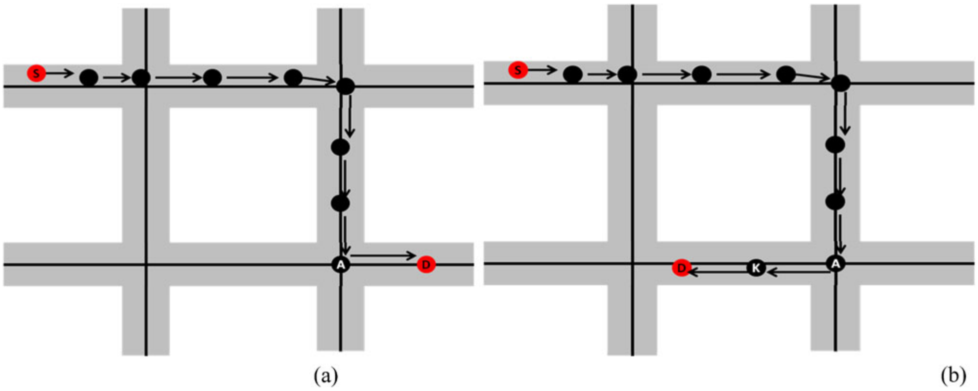


Fig. 5 (**a**) The source node ‘S’ communicates with the destination ‘D’ through ‘A’. (**b**) the source node ‘S’ communicates with the destination ‘D’ through ‘K’

DDREQs will reach to the destination and the others will expire after TTL. The intersection information is already fed to the nodes. At the other end, upon receiving a DDREQ, the destination will reply by sending a DDREP in the relative direction of the source. The destination drops all the DDREQs except the first DDREQ message. The DDREP is sent back to the source using the signature of intersections.

In Fig. 4, the source ‘S’ sends unicast DDREQ messages to all its directions (i.e. left and right here). In the left, ‘S’ chooses node ‘E’ and ‘E’ chooses ‘F’ as the forwarding node using SNESA accordingly. But ‘F’ reaches to the dead end. Hence packet is dropped. Similarly in the right direction, ‘S’ chooses ‘A’ as the forwarding node. The destination node ‘D’ is in the neighborhood of ‘A’. Hence the packet is delivered to ‘D’. Here the destination gets a DDREQ from the left direction, hence it replies with a DDREP message to its left direction finding appropriate forwarding node. The node ‘D’ uses SNESA to find an appropriate forwarding node in the left direction. The path of the DDREP is D → B → S. After getting the DDREP message, the source ‘S’ sends the data to its right by choosing appropriate forwarding nodes. Ultimately it reaches to the destination ‘D’. Every node on receiving a DDREQ/DDREP, extracts the direction information of other nodes. Here ‘S’ keeps information of ‘A’, ‘B’ and ‘D’. Node ‘B’ keeps the direction information of ‘S’ and ‘D’ and so on. If any node changes its direction, it is taken care by the destination direction update procedure which is explained in the subsequent section.

4.6 Destination direction update

In the previous section, it is discussed how every node keeps track of the relative direction of some other nodes. But nodes change their position which compels the change of relative directions. If position information of all the nodes is shared within the whole network, it would be a very costly affair in terms of network overhead. Rather information could be updated, whenever and wherever necessary. Even though no dedicated route is established from the source to the destination, there is a virtual path established between the source and the destination. Whenever the destination changes its direction, it is visible to all nodes in its neighborhood. The nodes which are aware of this change, update this information in their cache. By this process, any of the nodes communicating with the destination can carry out the communication in the changed direction without any interruption.

In Fig. 5(a), the source node ‘S’ is communicating with the destination node ‘D’ through node ‘A’. Node ‘D’ changes its segment in the middle of data transmission. As shown in Fig. 5(b), when node ‘D’ moves from the right segment to the left segment, the change can be noticed by node ‘A’ through the beacon message of ‘D’. Even though ‘D’ changes its segment, it will be at the neighborhood of ‘A’ for some time period. Hence node ‘A’ will change the direction of the destination from right to left. If node ‘D’ travels beyong the range of ‘A’, node ‘A’ can choose appropriate forwarding node in the actual direction of ‘D’. This is possible as node ‘A’ has already cached the updated direction of ‘D’. The direction information are updated from the most recent DDREQ, DDREP and HELLO messages.

5 Performance evaluation

The primary goal of the performance evaluation of DDOR in highway is to demonstrate the effect of speed and density of nodes on routing through simulations experiments. We compared the efficiency of DDOR protocol with some existing protocols in terms of performance metrics: packet delivery ratio, routing overhead and average end to end delay.

5.1 Routing metrics

We use the following as our routing metrics.

(1) Packet delivery ratio (%): It is ratio of total number of packets received at the destination to the total number of packets generated by the source.
(2) Routing overhead: It is the total number of routing packets for entire simulation period.
(3) Average end to end delay: It is the average time taken for each received packet.

5.2 Simulation environment

Periodic hello interval The periodic hello is decided upon the maximum velocity of the vehicles. Periodic hello message must be broadcasted by the fastest node at least once to cover its transmission radius (i.e. R distance). As per our simulation setup we take the maximum speed as 60 m/s and transmission range as 300 meters. Hence the beacon interval is set as 5 seconds for periodic beacons.

Milestone setup for positional hello If two nodes move in opposite directions in highest speed, one may not listen to other node’s beacon only with periodic hello. So we expect them to listen, at least twice each other’s beacon in 1 second time period. So the distance between two milestones is set as 150 meters (i.e. half of the transmission range).

In our future work, we will optimize the milestone setup and periodic beacon interval.

Other setup We have chosen freeway mobility model for our simulation scenario. For highway scenarios it is the most suitable mobility model. We have taken 100 to 800 nodes to find out packet delivery ratio, routing overhead and average end to end delay with variable maximum velocity from 20 m/s to 60 m/sec. The location service used in the simulation of GPSR is HLS [17]. We have implemented our protocol in NS-2 simulator [42]. For each simulation result we have executed on 5 Scenario files and took the average. Total three transmission pairs are selected for our simulation. The transmissions are initiated at different times but stopped with the end of simulations.

Table 3 Simulation parameters

Parameters	Values
Highway/Freeway length	3000 m
Number of lanes	4
Number of Nodes	100–800
Vehicle Speed (Minimum)	10 m/sec
Vehicle Speed (Maximum)	60 m/sec
Transmission Range	300 m
Data Rate	2 Mbps
Simulation Time	300 sec
Periodic Beacon Interval	5 sec
Number of Connections	3

5.3 Experiment and results

5.3.1 *Impact of Beacon interval and node density in GPSR*

In Fig. 6(a)–(e), we find PDR, routing overhead and average end-to-end delay of GPSR with variable speed and variable node density. Figures 6(a), 6(b) and 6(c) demonstrate packet delivery ratio of beacon intervals 0.6 second, 1.0 second and 2.0 seconds respectively. The packet delivery ratio starts dropping at different level for different beacon interval. They drop drastically after 400 nodes, 600 nodes and 700 nodes in Fig. 6(a), 6(b) and 6(c) respectively. In Fig. 6(a) from 400 to 700 nodes the performance is quite unstable. The reason behind such drastic degradation is the routing overhead. From Fig. 6(d), it is clear that the routing overhead is very high even though increasing linearly. As number of nodes increases, the periodic hello increases. From the simulations, we have found that at the 800 node density and with speed of 60 m/s, only 19 packets have been sent. Also we notice an interesting observation that the heavy contention state gets delayed with higher beacon interval. From Fig. 6(a), 6(b) and 6(c) we can conclude that with lower beacon interval the network exhausts early. The average end-to-end delay increases with speed and density which is evident from Fig. 6(e). Also in Fig. 6(e), we notice that the maximum delay is above 80 seconds. Increasing speed has less or no impact to the packet delivery ratio and routing overhead. Yet we can notice the average end-to-end delay increases with higher speed. In Fig. 6(e) for node density 700 on different speed, the delay gets increased and it is the maximum at speed 60 m/s.

5.3.2 *Impact of speed and node density on DSR*

Figures 7(a), 7(b), and 7(c) present the performance graphs of DSR in terms of packet delivery ratio, routing overhead and average end-to-end delay respectively. If we see the

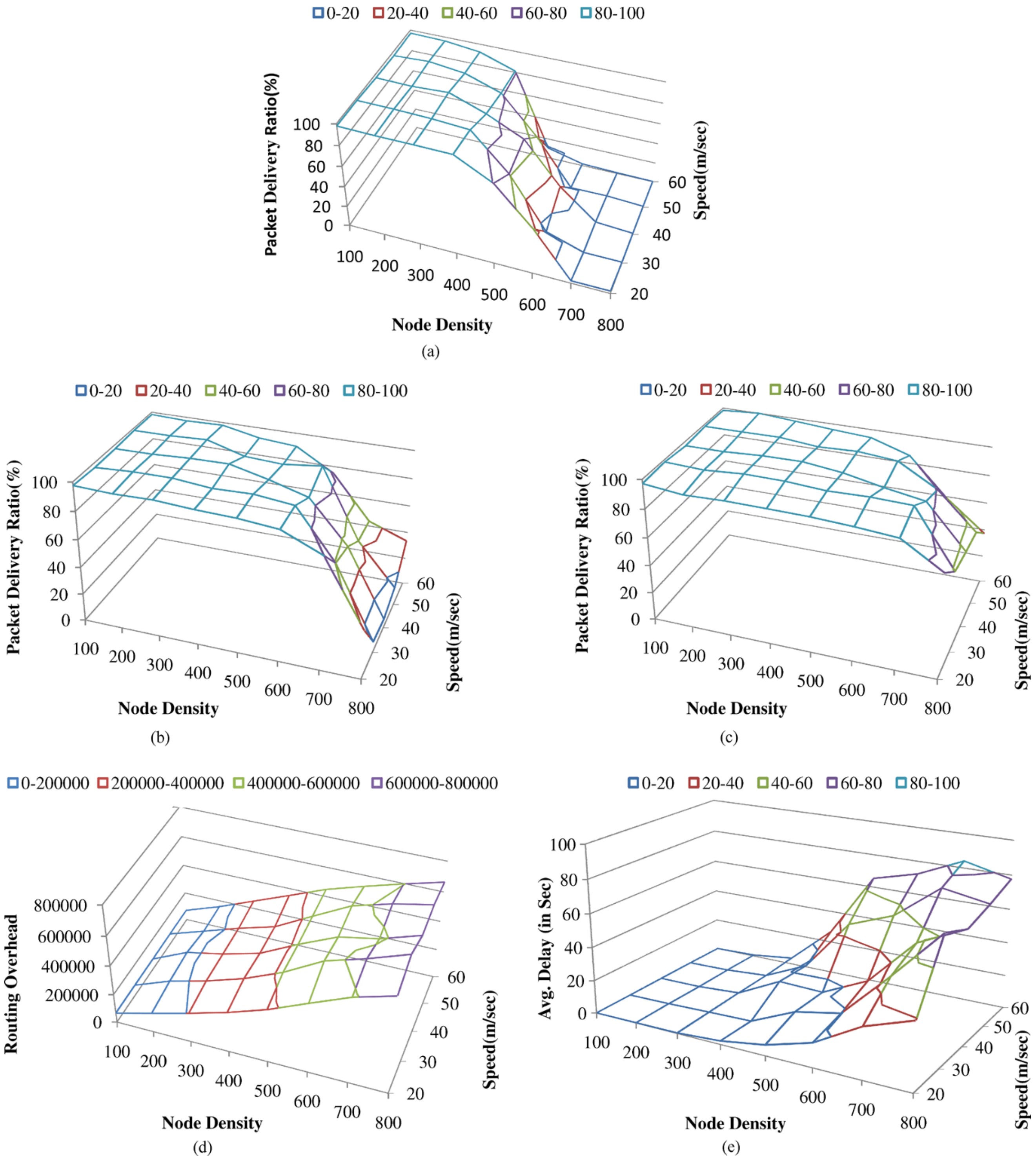


Fig. 6 (**a**) Packet Delivery Ratio of GPSR with Beacon Interval of 0.5 second. (**b**) Packet Delivery Ratio of GPSR with Beacon Interval of 1.0 second. (**c**) Packet Delivery Ratio of GPSR with Beacon Interval of 2.0 seconds. (**d**) Routing Overhead of GPSR with Beacon Interval of 0.5 second. (**e**) Average End-to-End Delay of GPSR with Beacon Interval of 0.5 second

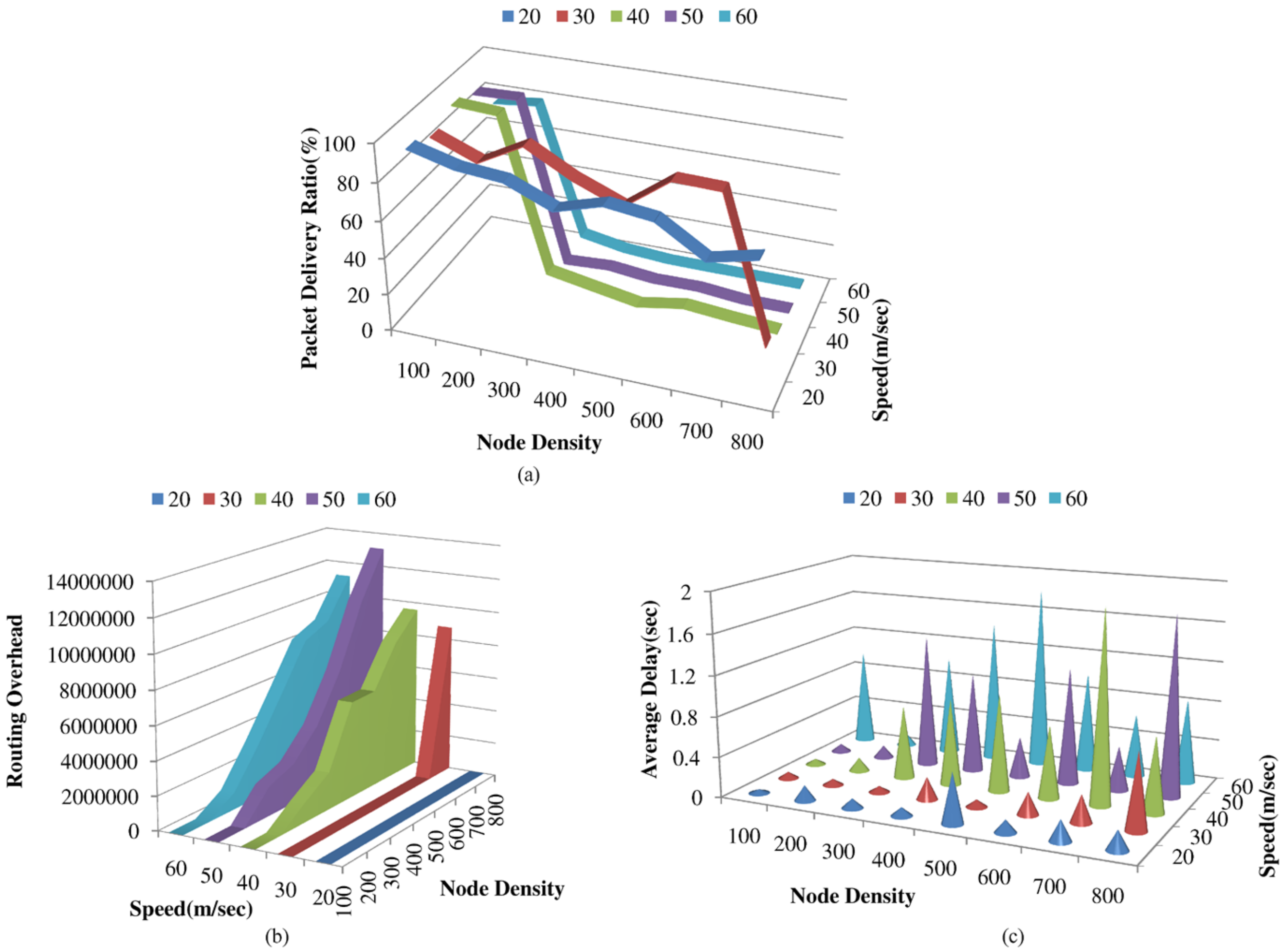


Fig. 7 (**a**) Packet Delivery Ratio of DSR. (**b**) Routing Overhead of DSR. (**c**) Average End-to-End Delay of DSR

packet delivery ratio of DSR, we can notice that it has been worst affected by both vehicle speed and node density. At speed 20 m/s, irrespective of node density the PDR is not below 65%. However up to 200 nodes, the PDR is not below 77%, irrespective of speed. At speed 30 m/s for 800 nodes the PDR reduces to 11% and at 40 m/s for 300 nodes the PDR reduces to 12%. This implies that speed has more immediate impact on PDR than node density. Every sharp increase in routing overhead as shown in Fig. 7(b) has immediate impact on PDR which is shown in Fig. 7(a). At speed 30 m/s for 800 nodes, the routing overhead is increased 422 times from its previous density. In DSR, when a route expires, it searches for alternative route from the route cache. However with increase in speed and node density the validity of route cache is decreased. This leads to heavy flooding, which increases routing overhead drastically. When we look into Fig. 7(c) for average end to end delay, it does not increase so quickly comparing routing overhead. Initially, the network is not congested. Before the network gets congested due to heavy contention, some of the packets have already been delivered to the destination. After that none of the packets get served. As we calculate the end-to-end delay of the received packets only, it does not increase drastically with increase in speed and node density.

5.3.3 *Impact of speed and node density in AODV*

In Fig. 8(a)–(c), we demonstrate the impact of speed and node density on AODV. In Fig. 8(a), 8(b) and 8(c) we have shown the performances in terms of packet delivery ratio, routing overhead and average end-to-end delay respectively. In our simulations, we have observed that AODV is the protocol where high node density has much lower impact compared to GPSR and DSR. In Fig. 8(a), we notice that the lowest PDR is 64% and the highest is 97%. The best performance is achieved at the speed of 20 m/s for 100 nodes and the worst performance takes place for 800 nodes at a speed of 60 m/s. This observation indicates that speed and density has impact on AODV. In Fig. 8(b) a number of spikes

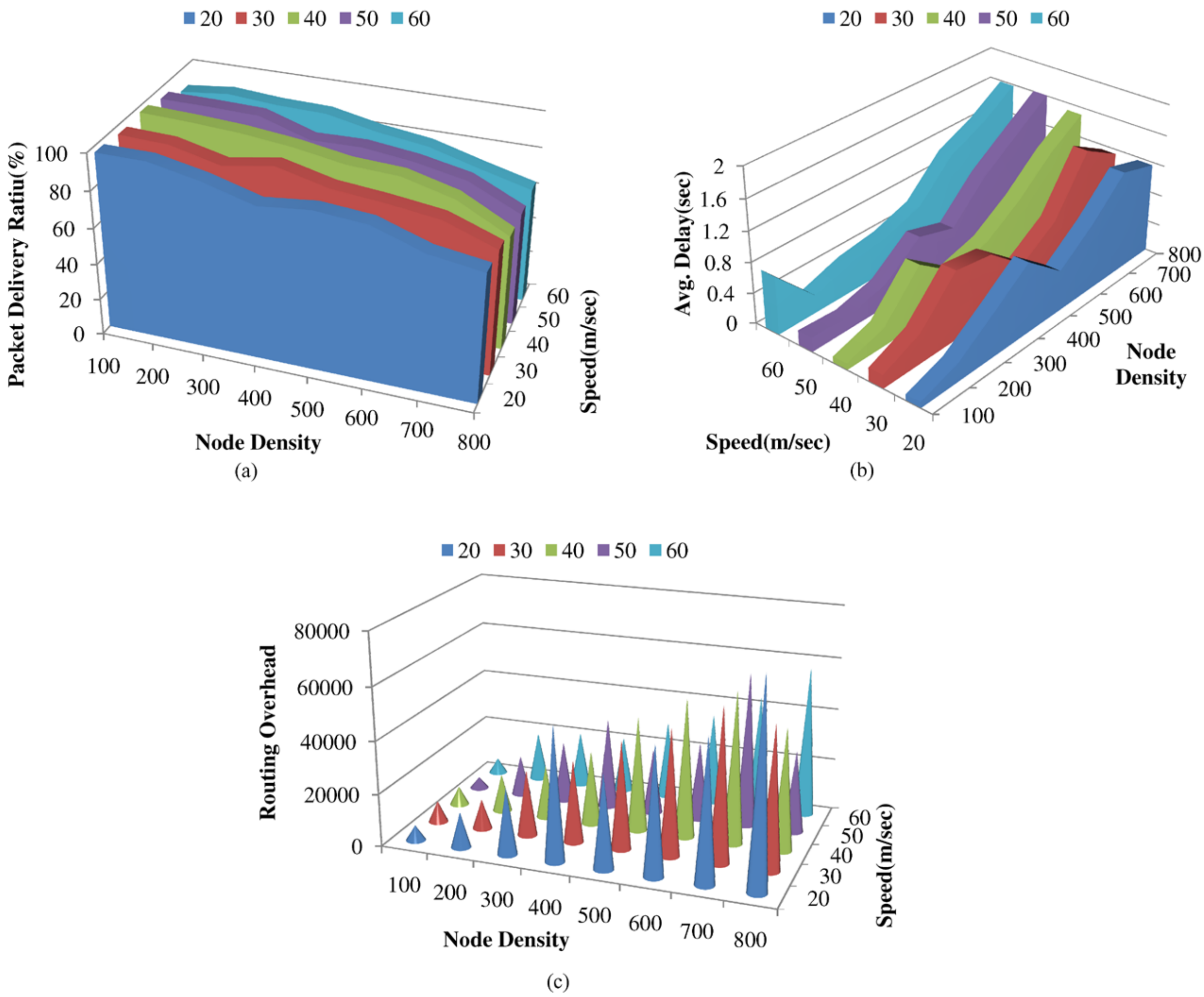


Fig. 8 (**a**) Packet Delivery Ratio of AODV. (**b**) Routing Overhead of AODV. (**c**) Average Endto-End Delay of AODV

can be viewed. For 400 nodes at the speed of 50 m/s we notice a spike. At the same point in Fig. 8(a), we notice a drop in PDR. Also at the same point in Fig. 8(c), we notice higher routing overhead. It is the impact of path maintenance of AODV. Similar situation happens for 400 nodes at speed 20 m/s. If we compare AODV with GPSR, we can visualize that AODV is better in high density scenarios. Also DSR has a lower performance compared to AODV except the average end-to-end delay. AODV establishes a path from the source to the destination. Once a path is established, every node on that path tries to keep track of its pre-hop and next-hop node. This is done by hello messages only if, no recent data packet is overheard. If a data packet is overheard at the beacon interval then the beaconing in skipped. Also AODV has auto adjustable beaconing. This is a wonderful concept which reduces the routing overhead. Neither GPSR nor DSR has such arrangement. This is the main reason why AODV has lower routing overhead compared to GPSR and DSR.

5.3.4 Impact of speed and node density on DDOR

In Fig. 9(a), 9(b) and 9(c), we analyze and demonstrate the PDR, routing overhead and average end-to-end delay of DDOR with variable speed and variable node density respectively. When we consider PDR, the Average PDR of DDOR is 97.49%. However in AODV, DSR and GPSR (BI = 0.5 sec) the average PDR are 84.79%, 46.69% and 56.6% respectively. From these data we can conclude that AODV is comparable to DDOR in terms of packet delivery ratio. It actually suffers when it has to do flooding for path break-up. There are two reasons why our protocol has better survival possibilities, one is the reduced number of beacons and the other is the unicast destination discovery. We can notice from Fig. 9(b) that the routing overhead increases pretty consistently. Even though AODV has similar routing overhead, it has occasional spikes which can also be seen in Fig. 7(c). Although our packet delivery ratio is very high, the observed delay is very small compared to AODV. When

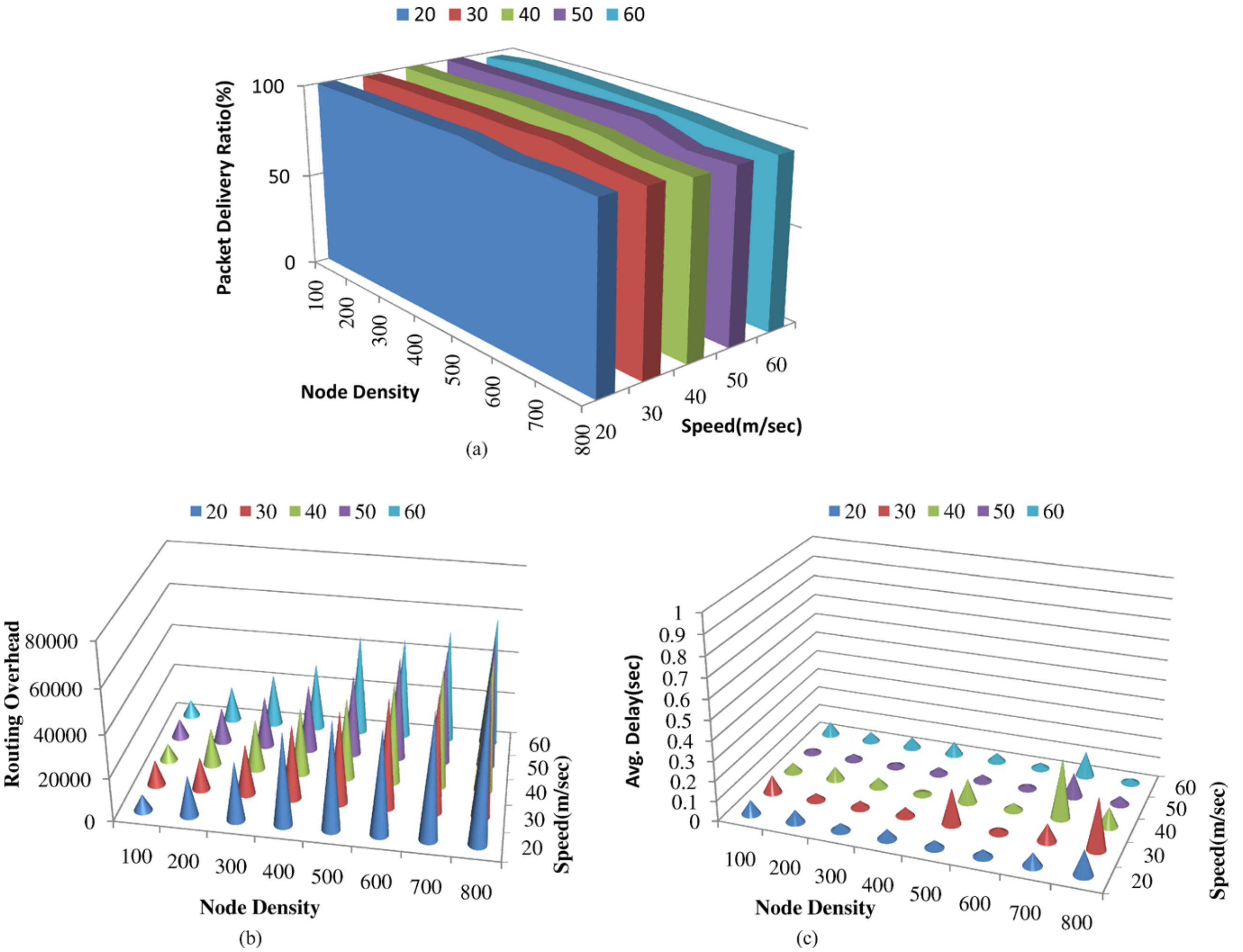
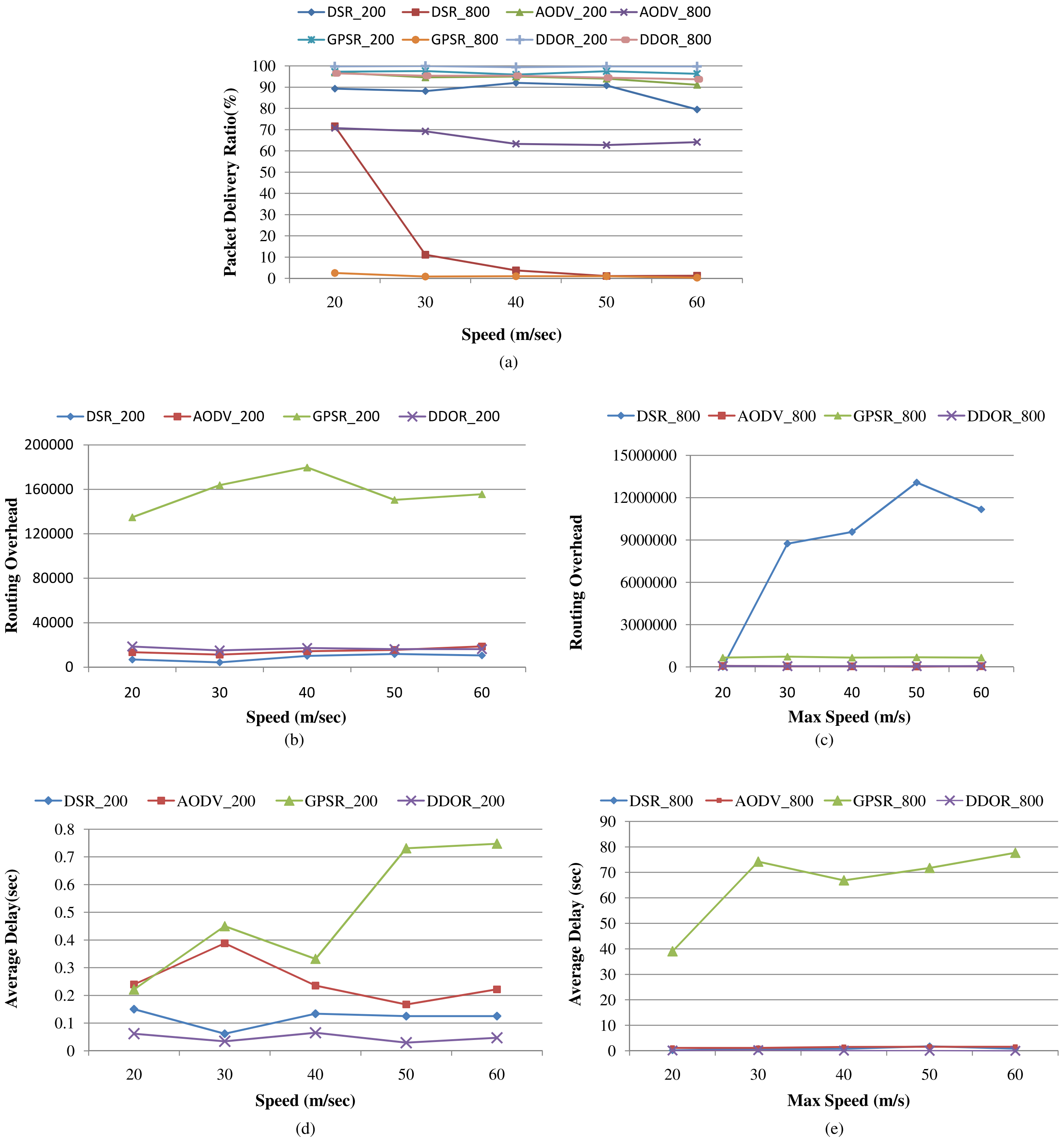


Fig. 9 (**a**) Packet Delivery Ratio of DDOR. (**b**) Routing Overhead of DDOR. (**c**) Average End-to-End Delay of DDOR

we consider average end-to-end delay in Fig. 9(c), the maximum and minimum delays are 0.3 second and the 0.01 second respectively. By the same time the maximum and minimum delay in DSR, AODV and GPSR (BI = 0.5 sec) are (1.9, 0.03), (1.6, 0.07), (84.1, 0.04) respectively. The average delay in DDOR, DSR, AODV and GPSR are 0.068 sec, 0.58 sec, 0.73 sec and 25.64 secs respectively. This shows that as per delay is concerned we are 8.5 times better than DSR, 10.73 times better than AODV and 394.46 times better than GPSR. AODV and DSR establish a route from the source to the destination without optimizing the hop count. With increase in hop count delay is increased. In case of GPSR, the high node density causes heavy network traffic, and data packets are rarely received at the destination. At every hop those packets have to wait for a longer time in queue. But we have tried to send our packet to the possible farthest node which reduces the hop counts. Hence we have much lower delay than other protocols.

5.3.5 *Impact of speed on different protocols*

In Fig. 10(a)–10(e), we compare relative performance of GPSR, DSR, AODV and DDOR with increasing speed for two set of node density (i.e. 200 nodes and 800 nodes). In Fig. 10(a) the packet delivery ratio is compared. For 200 nodes, AODV has 5.5%, DSR has 10% and GPSR has 1% performance skid. This exhibits the performance degradation of AODV and DSR with speed; where as in GPSR, the impact of speed is not seen. All the protocols have very high packet delivery ratio for 200 nodes. For 800 nodes, the impact of speed is more evident. Specifically if we look for DSR the performance degradation margin is 70%. Here also GPSR has very low degradation in performance with increase in speed. The reason is the accuracy of position information due to lower beacon interval. Although GPSR is unable to perform in very high density scenarios, it has a very high performance benchmark for low and medium den-



(a)

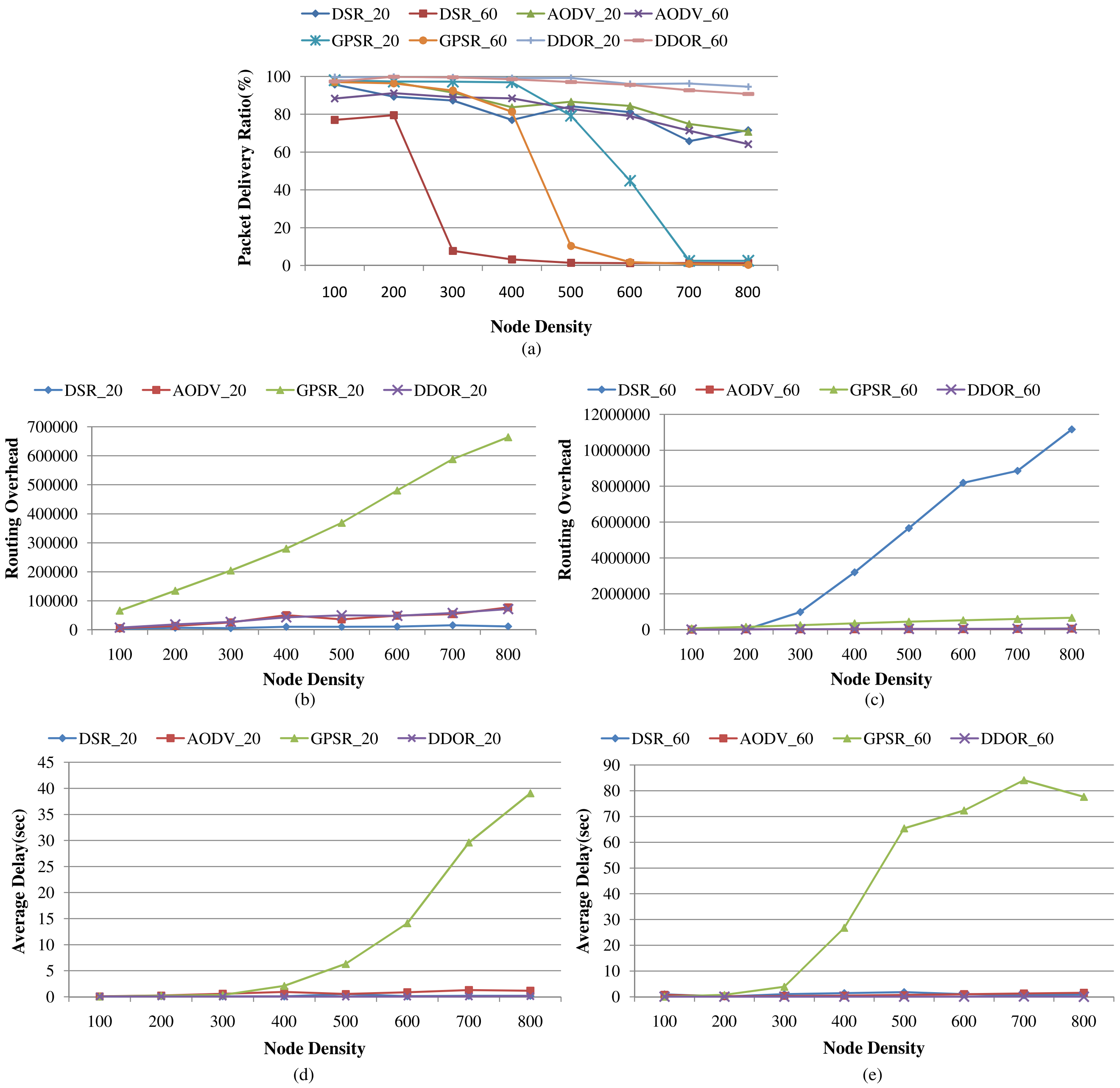
(b)

(c)

(d)

(e)

Fig. 10 Performance Comparison of DDOR with GPSR, DSR and AODV with variable maximum speed of vehicles (**a**) Packet Delivery Ratio Vs Speed with node density of 200 nodes and 800 nodes respectively. (**b**) Routing Overhead Vs Speed with node density of 200 nodes. (**c**) Routing Overhead Vs Speed with node density of 800 nodes. (**d**) Average End-to-End Delay Vs Speed with node density of 200 nodes. (**e**) Average End-to-End Delay Vs Speed with node density of 800 nodes



(a)

(b)

(c)

(d)

(e)

Fig. 11 Performance Comparison of DDOR with GPSR, DSR and AODV with variable node density of vehicles. (**a**) Packet Delivery Ratio Vs Node Density with maximum vehicle speed of 20 m/sec and 60 m/sec. (**b**) Routing Overhead Vs Node Density with maximum vehicle speed of 20 m/sec. (**c**) Routing Overhead Vs Node Density with maximum vehicle speed of 60 m/sec. (**d**) Average End-to-End Delay Vs Node Density with maximum vehicle speed of 20 m/sec. (**e**) Average End-to-End Delay Vs Node Density with maximum vehicle speed of 60 m/sec

sity scenarios provided no HOLE is present in between the source and the destination. At speed of 20 m/s for 800 nodes, the PDR of DDOR is 94%, and at speed 60 m/s, it is 91%. This indicates that speed has low impact on DDOR. Although two kinds of beaconing and one neighbor update algorithm is implemented, occasionally some nodes may slip out of the communication range. This is the reason for the 3% PDR performance slide.

In Fig. 10(b) and 10(c), the routing overhead is shown with increasing speed for 200 nodes and 800 nodes. For 200 nodes DSR has lowest routing overhead and GPSR has the highest overhead. However DDOR and AODV have similar routing overhead. These two protocols have slender increase in overhead than DSR. The overhead of GPSR is due to its heavy beaconing. But for 800 nodes AODV and DDOR are having almost same routing overhead where as GPSR has overhead 10 times higher than DDOR. At the same time DSR have a routing overhead above 100 times of DDOR.

In Fig. 10(d) and 10(e), the end-to-end delay is compared for 200 nodes and 800. For 200 nodes, GPSR has increasing delay from 0.2 second to 0.75 second. DSR has delay around 0.1 second and AODV has delay on or above 0.2 second. However DDOR has a delay around 0.05 second. However for 800 nodes, the average delays of AODV, DSR and GPSR and DDOR are 1.39 sec, 0.86 sec, 65 seconds, and 0.1 second respectively. The long delay of GPSR is due to the fact that all the packets keep waiting in queue looking for availability of free channel.

5.3.6 Impact of node density on different protocols

In Fig. 11(a)–11(e), we discuss the efficiency of different protocols with increasing node density for speed of 20 m/s and 60 m/s. In Fig. 11(a), packet delivery ratio of AODV, DSR, GPSR and DDOR is compared with increasing Node density. As already we have discussed, with increasing node density DSR and GPSR became unmanageable. This can again be confirmed from graph 11(a). At the speed of 60 m/s, DSR and GPSR have below 10% packet delivery ratio after 300 nodes and 500 nodes respectively. At the speed of 20 m/s also, GPSR has very low packet delivery ratio after 700 nodes. However AODV has less impact of node density compared to these two protocols. AODV has a performance degradation of 26% from 100 nodes to 800 nodes at speed of 20 m/s and performance degradation of 24% from 100 nodes to 800 nodes at speed of 60 m/s. For DDOR, the PDR is always above 91% irrespective of node density. The PDR of DDOR for 100 nodes is 99.7% and for 800 nodes is 94.5% at speed 20 m/s. Similarly for speed 60 m/s, for 100 nodes and 800 nodes the PDR values are 97% and 91% respectively. As compared to other protocols, DDOR is very less vulnerable to performance degradation with increased node density.

In Fig. 11(b) and 11(c) routing overhead is compared with node density for maximum velocity of 20 m/s and 60 m/s. With increased node density, GPSR has higher routing overhead. In DSR, for slow moving vehicles, the route cache validity would be there for any path break up. Therefore when the maximum speed is 20 m/s in Fig. 11(b), DSR could use its route cache effectively. Hence flooding was under control. This yields low control overhead and high packet delivery ratio irrespective of node density. But at speed 60 m/s uncontrolled flooding happened and it yielded higher control overhead and lower packet delivery ratio.

In Fig. 11(d) and 11(e), the average end to end delay of AODV, DSR, GPSR and DDOR is presented. In Fig. 10(d), at maximum speed 20 m/s and in Fig. 11(e) at maximum speed 60 m/s, the average end-to-end delay is calculated for different node densities. AODV, DSR and DDOR are able to keep their delay under control in both the figures. How ever the average delay of DSR, AODV and GPSR are 3 times, 11 times and 190 times higher than DDOR at maximum speed 20 m/s. Similarly, at maximum speed 60 m/s; DSR, AODV and GPSR are 17 times, 14 times and 724 times higher than DDOR respectively.

6 Conclusion and future works

In this paper, problems associated with routing in vehicular ad hoc network are presented. Most common issues are path break up, flooding, location service overhead and connectivity problems. While conventional routing protocols address to specific issues of vehicular ad hoc networks, we aimed to develop a robust protocol with high scalability. Our positional hello and periodic hello scheme really proved vital since it could maintain the neighborhood information without affecting routing overhead. Also high packet delivery and low end to end delay could be achieved. From the simulations it is demonstrated that our unicast destination discovery Process does not add much to routing overhead. SNESA algorithm ensured reduced hop counts. Reduced number of hop counts enabled lower delay. Also SNESA ensures successful delivery of packets. Our simulations confirmed that mobility and density do not have impact on the performance of the proposed algorithm and it outperformed AODV, DSR and GPSR in highway/freeway scenarios.

In the current work we focus on routing in Highway/Freeway for simulations. Although it has achieved better efficiency than some well known protocols, we have yet to test this with some other robust protocols. However, city scenarios are more diverse and challenging. The most difficult part is to coordinate among vehicles in the presence of many intersections. Hence the continuous efforts will be to implement our proposal in City Scenarios.

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